Andrew & Bannon

Tests of Reinforced Concrete Beams: Effect of Repetition of Load

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TESTS OF REINFORCED CONCRETE BEAMS
EFFECT OF REPETITION OF LOAD

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CHARLES EDWARD ANDREW
AND
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THESIS

FOR

DEGREE OF BACHELOR OF SCIENCE

IN

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U N I V E R S I T Y   O F   I L L I N O I S

May 29, 1906

This is to certify that the following thesis prepared under the direction of Professor A. N. Talbot, Head of the Department of Theoretical and Applied Mechanics, by

CHARLES EDWARD ANDREW and JAMES LEO BANNON

entitled TESTS OF REINFORCED CONCRETE BEAMS; EFFECT OF REPEATED LOADING

is hereby approved by me as fulfilling this part of the requirements for the Degree of Bachelor of Science in Civil Engineering.

Ira O. Baker.

Head of Department of Civil Engineering

Introduction.

The data and conclusions embodied in the following pages are the result of an investigation of the effect of the frequent repetition of a load upon reinforced concrete beams. A study has been made of the difference in effect upon different mixtures,- two beams of each of three different mixtures being used; also the effect of varying the ratio of the repeated load to the ultimate strength of the beam. For each beam an investigation was also made of the variations for different applications of the load in : 1. the position of the neutral axis; 2, unit deformations of steel and concrete; 3, deflections at the center. A study was also made of the probable condition of the steel and of the concrete at zero load after several applications of the load. The effect on the ultimate strength was also investigated by comparing the ultimate strength found in these tests with that of a similar beam broken by running the load up to the ultimate at the first application. The discussion of the methods and results is divided into the following divisions: 1. Introduction, 2. Description of Materials, 3. Description of Specimens, 4. Description of Tests, 5. Observed Data, 6. Discussion of Results, 7. Curves, 8. Tables of Original Readings.

2. DESCRIPTION OF MATERIALS

In order that these tests might meet the conditions found in ordinary practice all materials used therein (the sand, stone, cement and reinforcement) were all bought in the open markets.

The Stone:- The stone used in these tests is commercially known as Kankakee limestone. It is a good grade of stone and was ordered to be screened through a one inch screen and over a one-fourth inch screen. Tests show a trifle over 50% voids.

The Sand:- The sand used in these tests was taken from the Wabash river near Attica, Indiana, and is of representative quality. While not extremely sharp it is quite clean and well varied in size. The tests and the data following show the degrees of fineness and the per cent. of voids.

Fineness.

Sieve No.		% passing
4	-	100
10	-	73
20	-	36
50	-	12
74	-	5
100	-	2

Per cent. of voids in sand.

Ref No.	Wt. sand grams	Wt. water grams	Wt. mixture grams	% voids
1	1070	655	1240	26
2	1120	"	1315	30
3	1075	"	1265	29
4	1080	"	1255	27
5	1010	"	1190	28
			Mean -	28

Cement:- The cement used in the several mixtures is of standard brand Portland cement known comercially as Chicago AA Portland.

Results of 7 and 60 day tests standard briquettes are as follows:

No. of Briquette	Tensile strength lb. per sq. in.			
	Age 7 days		Age 60 days	
	Neat	1 - 3	Neat	1 - 3
1	634	283	890	443
2	717	281	916	440
3	732	275	840	422
4	687	217	942	365
5	580	206	872	352
6	731	189	885	---
Average	680	242	892	404

Metal:- The reinforcement used consisted of plain $\frac{1}{2}$" round bars. Test of material gave following results.

Yield point, lb. per sq. in.	34000 to 36000
Ultimate strength "	57000 to 59000
Elongation in 8"	27% to 30%

3. DESCRIPTION OF SPECIMENS.

The six beams used in these tests were 13 feet long over all,- 12 feet between supports. In cross section they were rectangular, 8 in. by 11 in. over all, with the center of gravity of the steel reinforcing bars 1 inch from the lower face, making the effective depth between the steel and the upper fiber 10 inches. The proportion of the steel , in terms of the cross-section area of the beam above the center of the bars was .98%. In each case there were four smooth round bars $\frac{1}{2}$ inch in diameter, the cross-section of the steel being therefore .785 sq. in., while the total cross-section area of the effective beam was 80.0 sq. in. The bars were placed in a horizontal position 2 inches apart center to center, with their axes in a plane parallel to the lower face of the beam and distant one inch from it. The mixtures proportioned ~~well~~ by loose volume , were 1-2-4; 1-3-5$\frac{1}{2}$; and 1-4-7$\frac{1}{2}$, there being two beams of each. The mixing was done by hand with shovels on a steel plate. The sand and cement were mixed dry, then the stone was thrown on and the whole mixed well again. Enough water was then added to make a moderately wet mixture. The concrete was tamped into the forms in layers of three or four inches. The forms were made of fairly smooth plank. In filling them the material was spaded around the edges to crowd the stone away from the plank thus allowing the mortar to form a smooth surface.

The age of the beams is given in the following table.

Age of beams.

Beam	Date of making	Date of test	Age	Age when forms removed	Age when moved from pos. on floor.
28	Dec. 15, 1905	Feb. 23, 1906	70 da.	4	14
29	"	" 24, "	71 "	4	14
30	"	" " "	71 "	4	14
31	"	Mar. 3, "	78 "	4	14
32	Dec. 16, 1905	" 5, "	79 "	4	14
35	Dec. 23, 1905	" 8, "	75 "	4	14

The above table shows age when forms were removed and also when beams were removed from their position on the floor. They were then stacked up one above the other with a few blocks between them to allow free circulation of air. They were not kept wet, but were allowed to dry naturally in a room in which the temperature ranged from 60 to 70 degrees Fahrenheit. They were moved from these piles to the testing machine by means of a hand crane.

4. DESCRIPTION OF TESTS.

The tests were made in the Laboratory of Applied Mechanics of the University of Illinois on an Olsen machine of 200000 lbs. capacity. The beams were set on rocking supports placed twelve feet between the centers, care being taken to see that the beam could move endwise thus preventing any end thrust due to deflection under load. Plates $3x\frac{3}{8}x8$ in. were placed between the rocker and the surface of the beam. The load was applied at third points which were determined accurately by measurement. At each of these load points a plate, similiar to those mentioned above, was placed across the top of the beam. On top of each of these plates a $1\frac{1}{2}$ inch roller was placed with its axis at right angles to the axis of the beam and directly over the load point. These two rollers were spanned by a ten inch I-beam, another bearing plate being placed between the beam and each roller. At the center of the top of the I-beam was placed a two inch roller which transmitted the load from the head of the machine to the beam. At each point of contact between the plates and concrete an even bearing was obtained by the use of a plaster of paris cushion. These cushions consisted of thin beds of plaster of paris in which the plates were set under slight pressure. The surfaces of contact between the rollers and the plates, and also between the rockers and the plates, were planed surfaces polished with emery paper to reduce resistance to rolling.

For measuring actual deflection of the beam at center a fine thread was stretched along one side between two screw heads, one at each end of the beam directly over the supports and 5 inches

down from the top of the beam. This thread was fastened at one end and kept taut by a suspended weight at the other end. A mirror scale, graduated to thirty-seconds of an inch was placed at the center of the beam behind the thread. The deflections were read by noting the position of the thread on this scale.

Deformations were read by the use of extensometers of the Johnson type, reading to one ten-thousandth of an inch. The four contact points of each extensometer yoke were placed in a vertical plane perpendicular to the axis of the beam between the support and the load point and four inches from the latter. The upper point was $\frac{1}{2}$ inch below top of beam and the lower point, $9\frac{1}{2}$ inches below the upper one, the upper rods being five inches above the top of the beam and the lower rods $5\frac{1}{4}$ inches below the center line of the steel. For description of extensometers in detail see Bulletin No. 1 of the University of Illinois Engineering Experiment Station, published September 1, 1904.

The load was applied in increments varying from 1000 to 6000 pounds, being run up and down 25 or 30 times as shown in the tables. Readings of extensometers and deflections were taken at each stop, the upper and lower pairs of the extensometers being read simultaneously.

As the test progressed the beam was carefully watched to detect the appearance of cracks however small, their size, location, direction and development, as well as the time of their first appearance being recorded. A record was also kept of the condition of the beam after failure.

5. OBSERVED DATA.

A record of the behavior of each beam is contained in the sketches, tables and curves which follow. In each case fine vertical hair cracks began to appear in the middle third of the beam early in the test. As the load increased during each application, the cracks opened, many of them being visible only while the full load was on. As the number of applications increased more and more cracks appeared, those which appeared first growing wider. A permanent set occurred at the end of the first application increasing with the number of applications. At the final repetition the load reached a maximum and then dropped slowly. The lower fibers elongated rapidly accompanied by the rapid widening of one or more cracks. Either at the maximum or shortly after it, the concrete crushed out at the top surface.

LOG OF BEAMS.

Skotches showing position of cracks and manner of failure of beams are shown on pages to inclusive.

Beam No. 28. 12 foot span

This beam was of a 1-2-4 mixture tested at an age of 70 days. Twenty five loads of 6000 pounds were applied in increments varying from 1000 to 6000 lbs. On the 26th repetition 1000 lb. increments were applied until failure. The first visible crack appeared at 6000 lbs. during the third repetition of load; this crack was very fine and completely closed when the load was released. A second crack appeared during the eighth repetition which also completely closed when the load was released. Two more hair cracks similiar to the ones mentioned appeared at the 13th and 26th repetitions respectively. When on the 26th repetition the load was run on above 6000 lbs. all of the cracks began to open further for a time, but more particularly the one numbered "8" in the accompanying diagram. The beam finally failed at 9900 lbs. by a decided opening of this crack at the bottom and crushing at the top. After failure the beam rapidly gave way under further application of load.

Beam No. 29. 12 foot span.

Beam No. 29 was a 1-3-5$\frac{1}{2}$ mixture tested at an age of 70 days. 29 loads of 5000 lbs. each were applied in increments varying from 1000 to 5000 lbs. The beam was loaded until failure on the 30th repetition. A fine hair crack was visible at 5000 lbs. in the first repetition. Two more appeared at the 2nd and 4th repetitions respectively. After the fourth no more cracks appeared

until the load had been increased to 6000 lbs. on the 30th repetition, when fine cracks appeared all along the bottom. As the load increased a large crack developed outside the north load point where the beam finally failed by diagonal shear at 10000 lbs. It is noted by reference to curves that the permanent set in the beam increased slowly during the test and that the deformations and deflections increased very rapidly after failure.

Beam No. 30. 12 foot span.

Beam No. 30 was of 1-4-7$\frac{1}{2}$ mixture. 30 repetitions of the load were applied, 5000 lbs. to the load, in increments varying from 1000 to 5000 lbs. On the 30th repetition the beam was loaded to destruction. The first cracks appeared in the third repetition when two fine hair cracks were visible. One of these near the center developed to a width of $\frac{1}{16}$ inch as the loads were repeated. During the fourth another crack appeared near the north load point. All these above mentioned closed almost completely when the load was released. During the 30th repetition a crack appeared at 5000 lbs. about 18 inches outside the south load point, which developed rapidly, the concrete splitting along the reinforcing bars to the load point and then cracking diagonally upward to the center and crushing out at the top. The failure was due to a slipping of the rods and occurred at a load of 5900 lbs. The beam gave way rapidly after failure.

Beam No. 31. 12 foot span.

Beam No. 31 was of a 1-2-4 mixture. A load of 6000 lbs. was applied in increments varying from 1000 to 6000 lbs. A peculiar feature of this beam and of No. 28 of the same mixture is that

the steel retains more permanent set as the test progresses than does the concrete. The first visible crack appeared on the second repetition. Other hair cracks appeared during the 5th, 7th, 10th and 25th repetitions. As the load increased above 6000 lbs. in the 25th repetition cracks No. 2,5, and 10 rapidly widened. At about 8000 lbs. 5 and 10 ceased to open and No. 2 opened more rapidly causing the beam to fail in tension at the bottom and crush out at the top as shown in sketch. The maximum load was 9400 lbs. This beam seemed to stand quite well after the maximum, holding the load well for considerable time after the maximum.

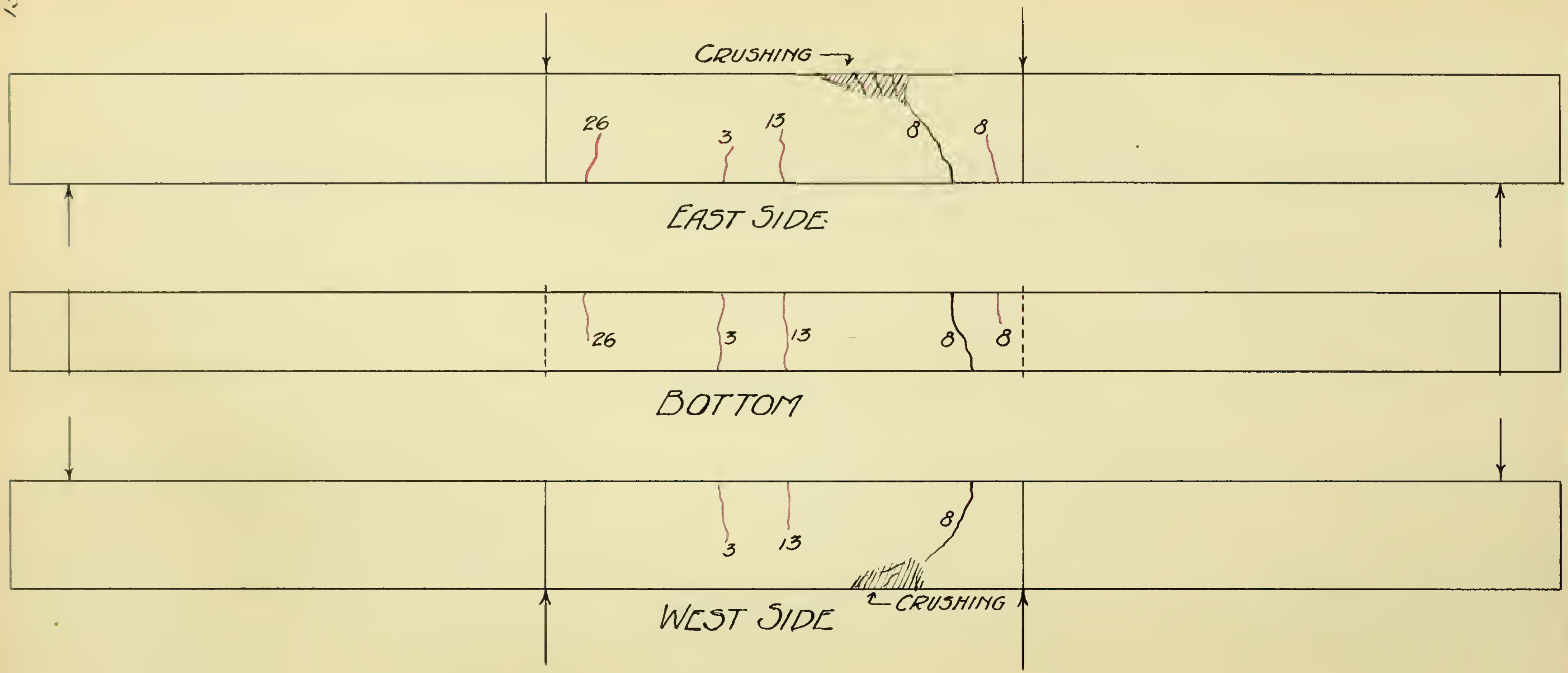
Beam No. 32.

Beam No. 32 was a 1-3-5$\frac{1}{2}$ mixture. 23 repetitions of 6000 lbs. were applied; the beam being loaded to destruction on the 24th repetition. It was particularly noticeable that in this beam the concrete retained set much more rapidly than did the steel. Two hair cracks appeared during the first repetition which completely closed on removing the load. During the sixth repetition two more similiar cracks appeared and still others in the seventh and ninth. When the load was increased above 6000 lbs. in the 24th repetition a crack appeared near the north load point which rapidly widened as the load increased, finally resulting in a failure by tension, the concrete failing by crushing just after the maximum was reached. This beam held the load well after the maximum, the beam being deflected nearly an inch with a decrease in the load of about 1500 lbs. after maximum.

Beam No. 35. 12 foot span.

This beam was of a 1-4-7$\frac{1}{2}$ mixture. A load of 5000 lbs. was

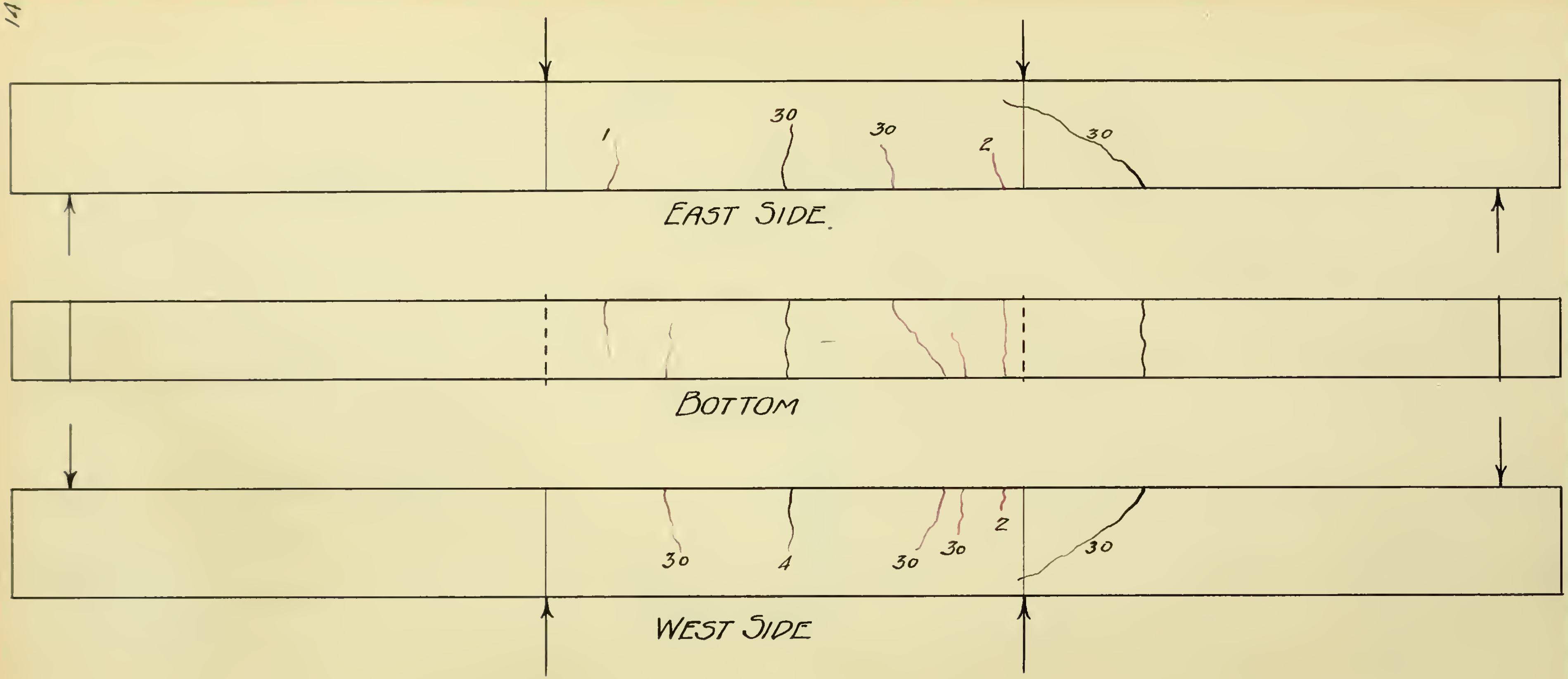
repeated 29 times. The beam was tested to destruction on the 30th repetition. Fine hair cracks appeared on the first repetition near the center, one of these finally developing into failure. Other fine cracks appeared on the 5th, 8th, 14th, and 15th repetitions as shown in the sketch. when the load was increased above 5000 lbs. in the 30th repetition crack No. 2 in diagram rapidly opened and caused failure at 7500 lbs. by crushing out at the top. This beam gave way quite rapidly after maximum.



EXPLANATION

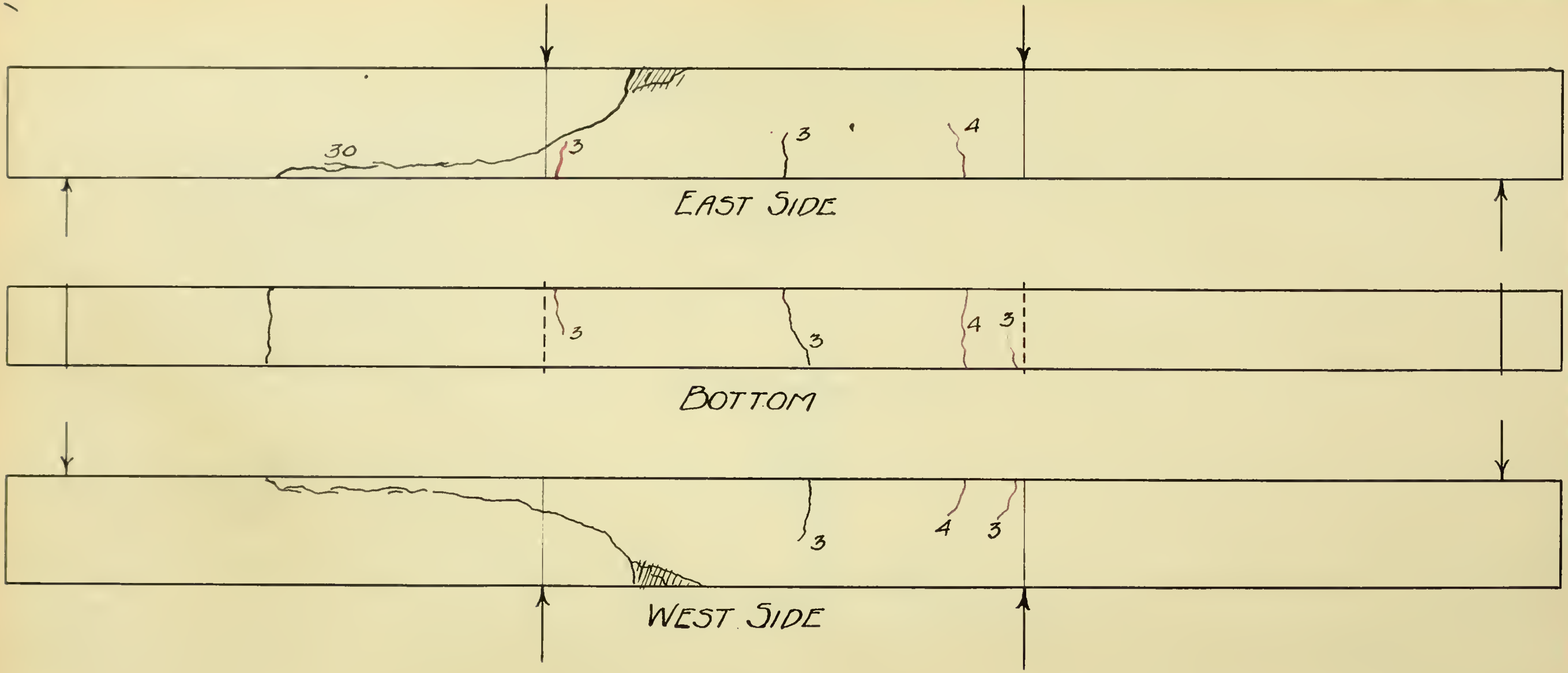
Cracks shown in red are hair cracks, those in black 1/50 of an inch or over. Sketch represents beam at failure. Numbers indicate application at which cracks first appeared.

BEAM Nº 28
MIXTURE, 1-2-4.
ULTIMATE STRENGTH, 9900
REPEATED LOAD, 6000
Scale, 3/4 in.=1 ft.



NOTE:
For explanation see 28.

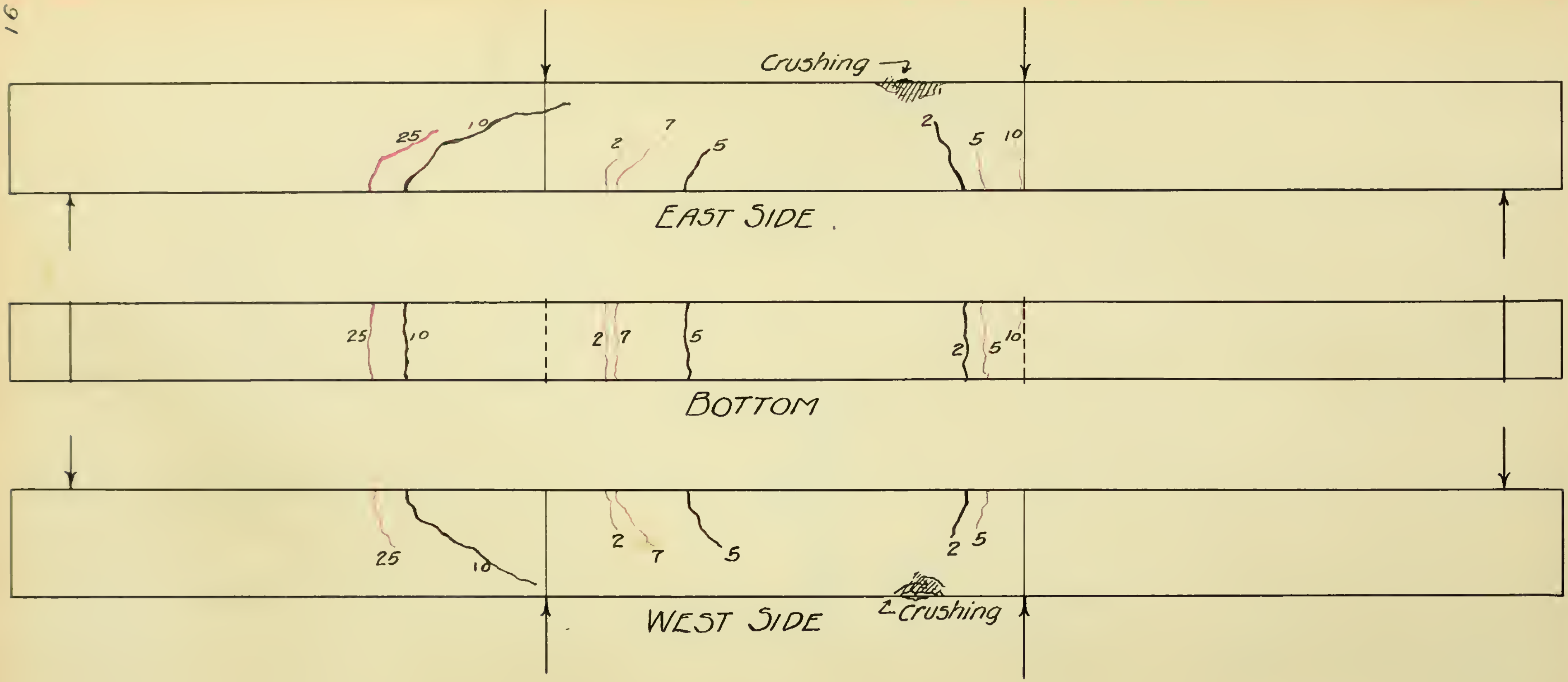
BEAM No 29.
MIXTURE, 1-3-5½.
ULTIMATE STRENGTH, 10000
REPEATED LOAD, 5000.
Scale, ¾ in. = 1 ft.



BEAM Nº 30.

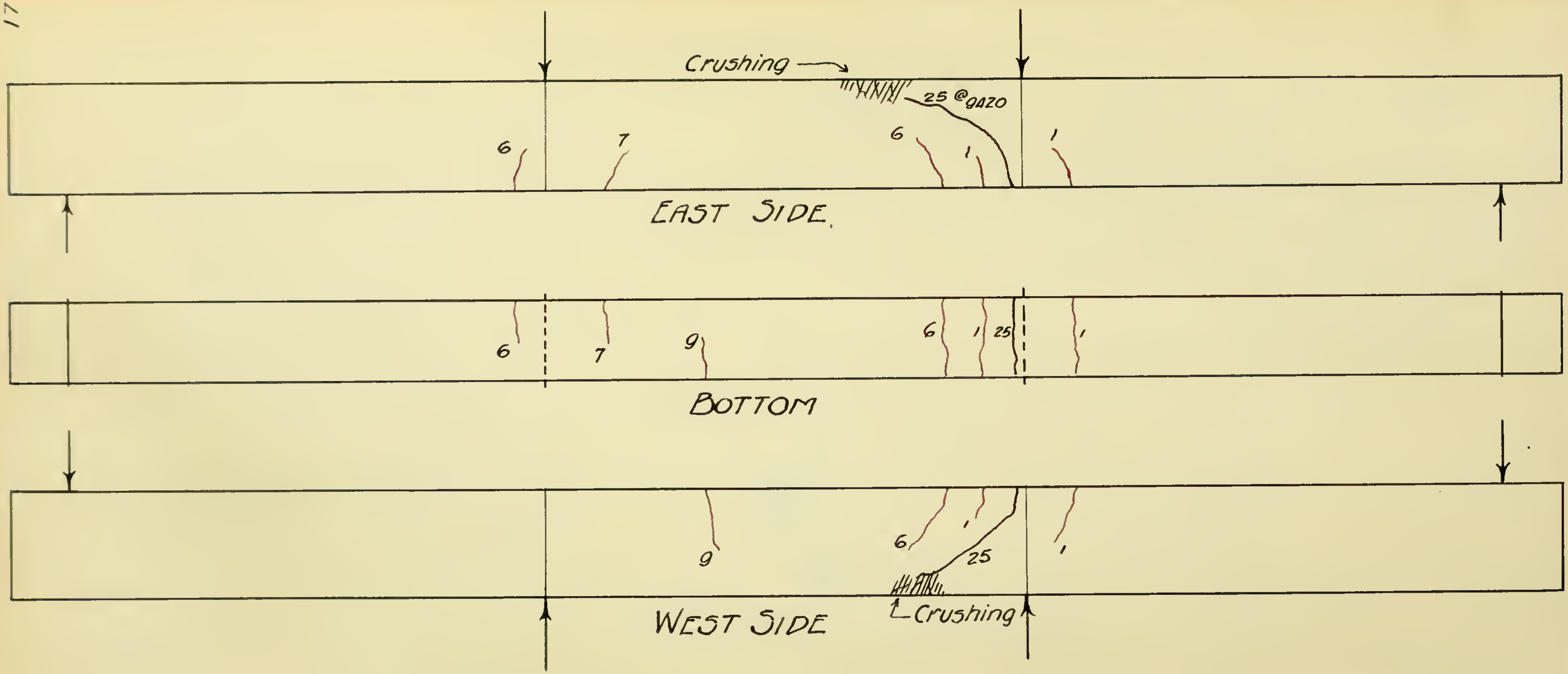
MIXTURỤE, 1-4-7½.
ULTIMATE STRENGTH, 5900
REPEATED LOAD, 5000.
Scale, ¾ in. = 1 ft.

NOTE:
FOR EXPLANATION SEE 28.



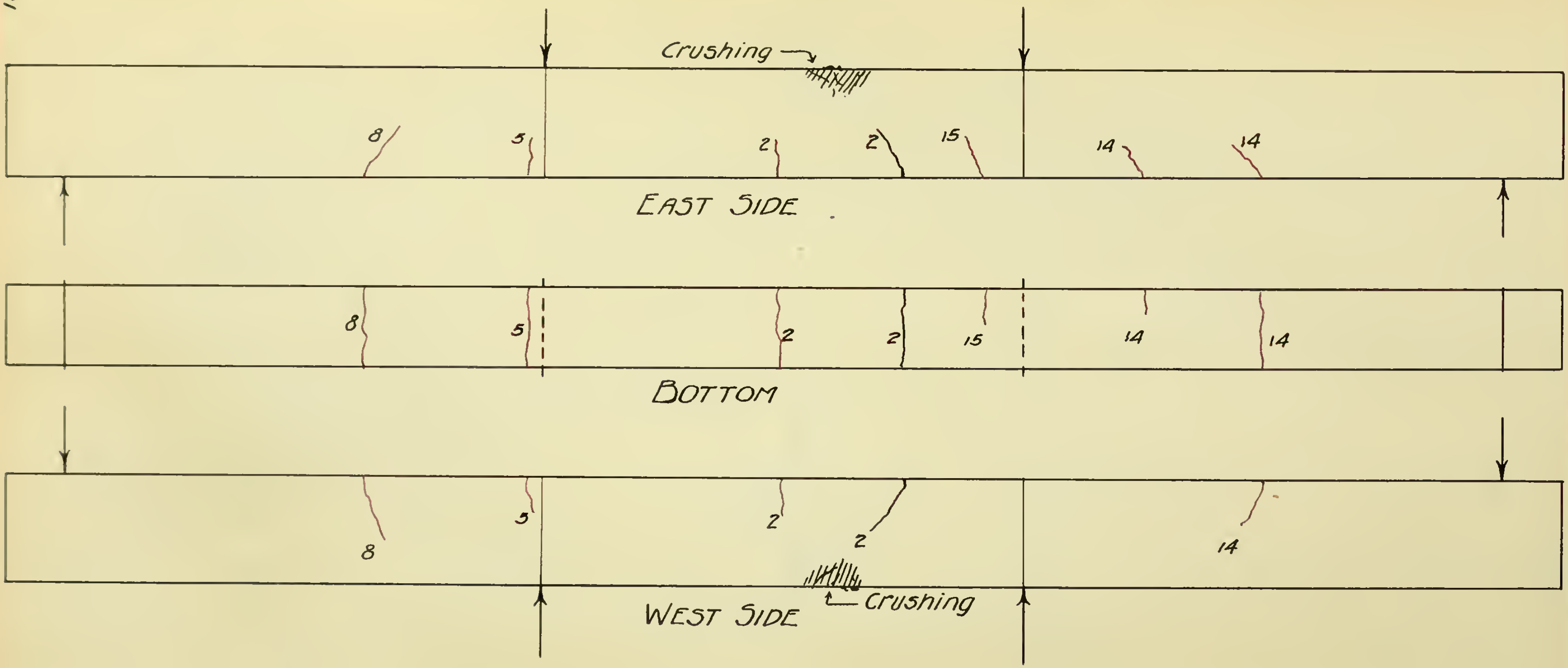
NOTE:
FOR EXPLANATION SEE 28.

BEAM No 31.
MIXTURE, 1-2-4.
ULTIMATE STRENGTH, 9400
REPEATED LOAD, 6,000
Scale, 3/4 in.=1 ft.



BEAM NO. 32.
MIXTURE, 1-3-5½
ULTIMATE STRENGTH, 9800
REPEATED LOAD, 6000
Scale, ¾ in.=1 ft.

NOTE:
For explanation see 28.



BEAM No. 35.

MIXTURE, 1-4-7½.

ULTIMATE STRENGTH, 7500

REPEATED LOAD, 5000.

Scale, ¾ in. = 1 ft.

NOTE:

For explanation see 28.

6. DISCUSSION OF RESULTS.

In plotting curves for these experiments it was found that there was an apparent error in some of the extensometer readings. The error must have been in the working of the instruments as considerable care was taken in setting them up and reading them. For example, extensometer dial No. 2 in the case of Beam No. 28 showed practically no advance between the 3000 lb. and the 6000 lb. loads on the first repetition, while the reading of each of the others at 6000 lbs. was about 150.0% greater than at 3000 lbs. This could not be due to a twist in the beam, because in that case one of the other extensometer dials would have shown a similiar tendency. On the other hand, when the load was released No. 2 went back as fast as the others. These two circumstances would seem to indicate that there was an impediment to the motion of the dial in one direction and not in the other. There could be no doubt that the readings of this extensometer dial were unreliable and therefore they were not considered in the compilation of results. Similiar dificulties were experienced with this and other extensometer dials in the tests of the other beams. Accordingly, for Beam No. 28, No. 2 was not considered; for Beam No. 29, Nos. 1 and 2 were not considered; for Beam No. 31, No. 2 and for Beam No. 35, Nos. 3 and 4 were neglected. In cases where all of the readings were considered, the true deformation at the top fiber was taken as the average of the readings of dials 1 and 3, and that of the steel was taken as that of the average of 2 and 4. There was no case in which both 1 and 3 or 2 and 4 had to be neglected. When either 3 or 1 had to be neglected the other was taken as the average, the same being done in the case of 2

and 4. These irregularities render all of the data more or less unreliable.

Effect on Ultimate Strength:- Because of the fact that there was an apparent permanent set in the beam after the first application of the load and that this set increased with each succeeding application, it might be supposed that the beam was gradually being weakened by the repetition of the load. It was hoped that this supposition might be investigated by comparing the ultimate strengths found in these tests with those of similiar beams not submitted to a repetition of the load. A comparison was obtained for only one mixture, the 1-2-4. The average maximum applied load for this test after 25 repetitions was 10000 lbs. while the average for a number of similiar beams tested without repetition was about 12000 lbs. The decrease in this case was about 15%. No data was available for further comparison.

Stresses Developed in Steel.

(a) Residual:- In all cases there was an apparent permanent set in the steel after the first application of the load, which generally increased continuously with the number of applications. In all cases it will be noticed from the accompanying curves that the deformation curve for the steel up to about 1000 lbs. load in the first repetition runs more nearly vertical than during the remainder of its course. From this it is concluded that since the concrete has a very low tensile strength it failed in the immediate vicinity of the steel soon after a load was applied; the steel having a much higher elastic limit continued to elongate through the remainder of the repetitions while minute cracks

opening in the concrete. When the load was decreased to zero, the steel not having been strained to its elastic limit tended completely to regain its former length. The minute cracks which had been formed could not be completely closed on account of small irregularities in the surface, and the steel could not therefore completely return to its former length and shape. Thus considerable compressive stresses were set up in the concrete adjacent to the steel and opposing this, an equal tension in the steel.

Assuming that there is no slip in the bond between the steel and the concrete, the stresses in the steel may be found from the following formula:-

Unit stress = coefficient of elasticity x unit deformation.

in which the coefficient of elasticity is assumed to be 30000000 lbs. per sq. in. and the unit deformation is computed from the tables. The accompanying data gives deformations on the basis of .785 sq. in. cross section of metal. Therefore since deformation varies inversely as the cross section for the same load, the unit deformation for any case is obtained by multiplying the deformation given in the following tables by .785. The maximum unit stress in the steel at zero load as computed by the above formula are given in the following table: (next page)

Mixt.	Beam No.	No. of repetitions at which maximum occurred.	Load applied. Pounds.	Apparent elongation at zero load.	Maximum unit Stress. (Pounds per sq. in.)
1-2-4	28	25	.000	.00056	16800*
"	31	24	"	.00030	9000
1-3-5½	29	5	"	.00014	4200
"	32	2	"	.00017	5100
1-4-7½	30	29	"	.00027	8100
"	35	1	"	.00010	3000

* Apparently greatly in error.

From the above table it may be noted thst the residual stress or stress at zero load, reached its maximum at the end of the last repetition for the 1-2-4 mixture. While in the proper mixtures it was generally a maximum in the early part of the test. It is probable that in the poorer mixtures the tension in the steel was sufficient to crush more nearly back into place the fine hair cracks which developed in the first application of load. It is noticeable by a study of the data that in some cases, especially in Beam No. 35, the permanent set developed at the first repetition decreased as the test progressed. It is probable that by repeatedly crushing, on repeatedly relieving the load the residual stress in the steel was sufficient to bring openings formed on the first repetition more and more nearly back to a closed position.

(b) Under Applied Load.

An attempt has been made to gain some information concerning stresses in the steel at different times under applied loads. It is possible to find these stresses in two ways:-

First. By the formula

$$S = Es$$

in which S = unit tensile strength in steel. E = coefficient of elasticity, and s = unit deformation in steel.

Second. By resilience (?). The internal resisting moment of the beam must equal the external moment to insure equilibrium, consequently the external moment may be equated to the internal moment as follows:-

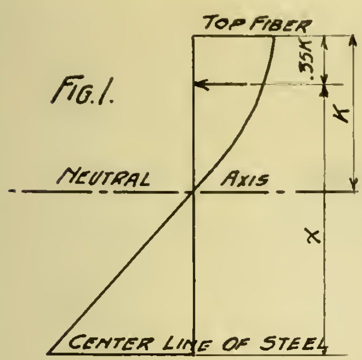


Fig. 1.

By formula heretofore deduced from experiments it has been found that the center of pressure of compressive stresses in the concrete lies .35K (Fig. 1) below the top fiber. Since the center of tensile stress is at the center of the steel, the moment arm of the internal couple is equal to the distance x, Fig. 1. x = d(1 - .35 K) where "d" is the effective depth of the beam, that is, the distance from the center of gravity of the steel to the top fiber, and K is the ratio of the depth of the neutral axis below the top fiber to the effective depth of the beam.

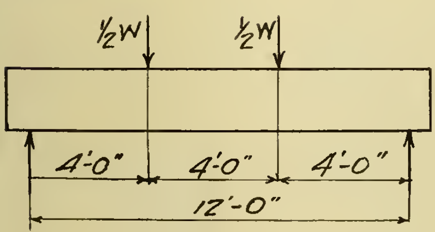


Fig. 2.

The maximum external moment is the same for all points in the middle third (Fig. 2) and in all cases for loading and span as shown above is $M = (\frac{1}{2}w)(4 \times 12)$ in. lbs.

(1) $M = 24\ w.$ in. lbs.

Let M' = the moment of the internal couple or resisting moment; then since the moment arm of this couple (x) Fig. 1 = d(1 - .35K) as explained above, the internal moment = the stress in the steel x d(1 - .35K).

(2) $M' = S'[d(1 - .35K)]$

Where S' = total stress in .785 sq. in. area of metal. Since the steel has an area of .785 sq. in. it will be necessary to divide the total stress by .785 to get the stress per sq. in.

(3) $M = M'$

Sub (1&2) $24\,w = S'[d(1 - .35K)]$

$$S' = \frac{24w}{d(1 - .35K)}$$

$$S = \frac{24w}{d(1 - .35K).785}$$

Where S = unit stres in the steel. Stresses have been figured by each method at the end of the first repetition for the maximum repeated load and at the maximum load after the last repetition as indicated in the table below.

Computed Data On Beams.

Beam No.	Mixt. of Concrete	No. of repetition	Neutral axis	Load lbs.	Bending Moment In. lbs.	Deformation in steel in.	Stress in Steel lbs. per sq. in. S=Es	Stress in Steel lbs. per sq. in. By moments $S=\frac{24\,w}{d(1-.35K).785}$
28	1-2-4	1	.430	6000	144000	.00069	20600	21700
"	"	26	.355	9900	237500	.00183	54900	47000*
29	1-2-5½	1	.470	5000	120000	.00044	11600	11300
"	"	30	.551	10000	240000	.00101	27500	23400
30	1-4-7½	1	.654	5000	120000	.00055	15900	19600
"	"	30	.720	5900	141000	.00071	21000	23850
31	1-2-4	1	.535	5000	120000	.00050	14400	14780
"	"	30	.488	9400	225000	.00120	36000	34600*
32	1-3-5½	1	.486	6000	144000	.00053	15900	17400
"	"	24	.656	8000	192000	.00072	21400	24900
35	1-4-7½	1	.600	5000	120000	.00049	14900	15200
"	"	30	.735	7500	180000	.00068	21000	24100

* Near elastic limit.

It may be seen from the above table that with but few exceptions neither method of computation showed a stress beyond the elastic limit of the steel, 35000 lbs. per sq. in.

Condition of Concrete. From a study of the curves and data of these tests it is seen that on the first application of the load a permanent set occurred in the upper fiber which, in all cases but one, was considerably greater than that in the steel.

It is also noticed that in all cases this permanent set increases quite uniformly with the number of repetitions. The only apparent reason for this set is the extremely low value of what may be called the elastic limit of concrete. The concrete being at first a somewhat porous mass was somewhat compacted by the applied load, the elastic limit being passed before the full load was on. As a result, there is at each application and release a diminishing tendency to return to its original state, the permanent set increasing at each repetition.

Effect of Varying the Ratio of Repeated Load to Ultimate Strength. It is noted that the deformations and deflections increased more rapidly when the repeated load was nearer the ultimate. This is especially noticeable in the case of Beams No. 30 and 35. In Beam No. 30 the repeated load was 85% of the ultimate strength while in Beam No. 35 it was only 67% of the ultimate strength, the mixture and the repeated load being the same in both cases. By reference to the accompanying curves and the table below it will be seen that the deformations increased much more rapidly in Beam No. 30 than in Beam No. 35.

Tablo Showing Effect of Difforonce in Ratio

of Repeated Load to Ultimato Strength.

Mix-ture	Beam No.	% Increase in Deformation. Greatest over Smallest. Steel	Upper Fiber	Ratio of Repeated Load to Ult. Str.
1-4-7-$\frac{1}{2}$	35	27.6	36.8	67%
"	30	33.8	44.6	85%
1-3-5$\frac{1}{2}$	29	15.4	49.7	50%
"	32	39.8	160.0	61%
1-2-4	28	59.8*	24.0	60%
"	31	28.0	24.0	64%

* Exception.

With the one exception noted the results in the above table seem to establish the fact that the greater the repeated load in proportion to the ultimate strength the more destructive is the effect of repeating the load.

Position of Neutral Axis. Curves have been plotted on a co-ordinate sheet for each beam showing position of the neutral axis following it through several repetitions of the load including the last.

It is noticed that in each case as the load increased from zero to full load the neutral axis curve rises, when the load is released again to zero the curve falls and at each succeeding zero it is lower th n at the zero previous. This is especially true in the poorer mixtures, due to the fact that there is more permanent set in the concrete and less apparent strain in the steel. It is seen from Fig. 3 that as x grows greater in proportion to y, the intersection of the lines ac and bd, fixing the position of the neutral axis, comes nearer to c.

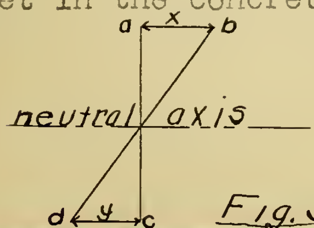


Fig. 3.

Curves have been plotted for each beam with the numbers of repetitions as abscissas and the distance of the neutral axis down from the top of the beam as ordinates, the curves being plotted for the maximum repeated load, in some cases 5000 lbs' and in the rest, 6000 lbs. It will be noted from these curves that the average depth of the neutral axis was about .45 for the 1-2-4 mixtures between .50 and .60 for the 1-3-5½ mixtures. and between .60 and .70 for the 1-4-7½ mixtures. This is probably due to the fact that the poorer mixtures have a lower modulus of elasticity than the richer ones.

It will be seen from Fig. 3 that the neutral axis may be lowered in two ways; (1) by increasing the deformation of the upper fiber, and (2) by decreasing the deformation of the lower fiber. Since the steel is the same in all cases, the only difference in deformation must occur in the upper fiber.

From the formula

$$E = \frac{\text{unit stress}}{\text{unit deformation}}$$

it is seen that when the unit deformation is increased, the modulus of elasticity is decreased, unit stress remaining the same in all cases.

Since it known that the unit stress remains the same in all cases and that the unit deformation inthe poorer mixtures is greater than in the better mixtures , it is evident that the modulus of elasticity must be less in the poorer mixtures than in the better.

Conclusion. The results and conclusions of this thesis may be summarized as follows:

1. The ultimate strength of a reinforced concrete beam such as those used in this work is probably reduced by repeating 25 or 30 times a load from one-half to two-third its ultimate strength.

2, When a reinforced concrete beam is loaded sufficiently to exceed the tensile strength of the concrete and the load then removed, a residual tensile stress is present in the reinforcing bars.

3, The greater the repeated load in proportion to the ultimate strength of the beam the more destructive is the effect of repeating the load.

4. The poorer the mixture the lower the neutral axis under the load.

EXPLANATION OF CURVES.

On pages 31 to 37 inclusive, are curves showing (1) the rate and extent of deformation in the steel and concrete throughout the test, (2) the position of the neutral axis throughout different series of loads, (3) the deflections at center.

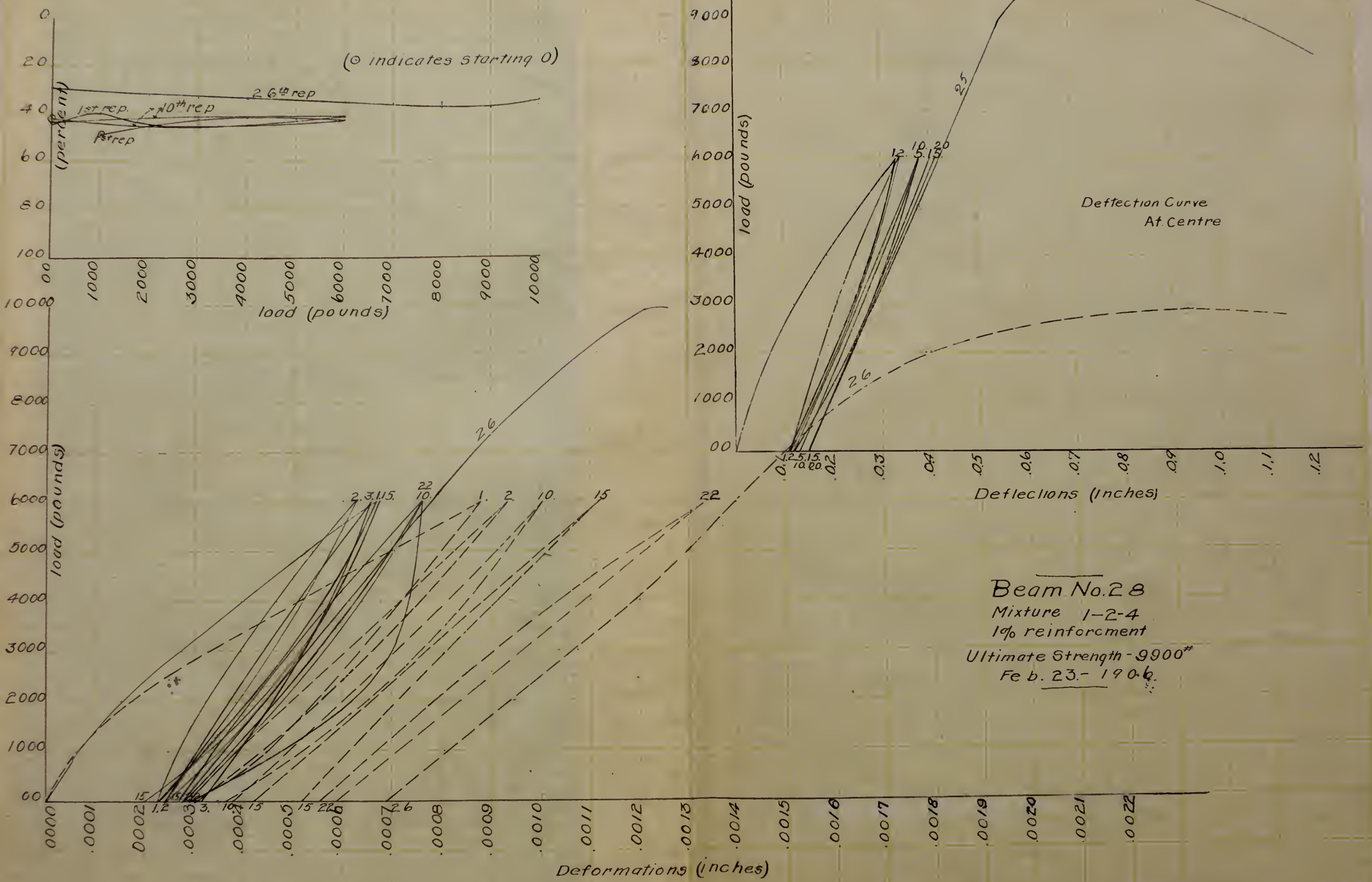
The deformation curves show the deformations per unit of length in both the steel and concrete, the curves for the steel being shown by a broken line and those for concrete by a solid line. Unit deformations were used as abscissas and the loads as ordinates. to avoid confusion of lines curves were plotted for only about every fifth repetition or series of loads, the first and last being included in every case.

The neutral axis curves are plotted with the loads in pounds as abscissas and, as ordinates, the ratio of the depth of the neutral axis below top of beam to the effective depth of beam. These curves show the positions of the neutral axis throughout several repetitions following the zero load to the full repetition load and back to zero.

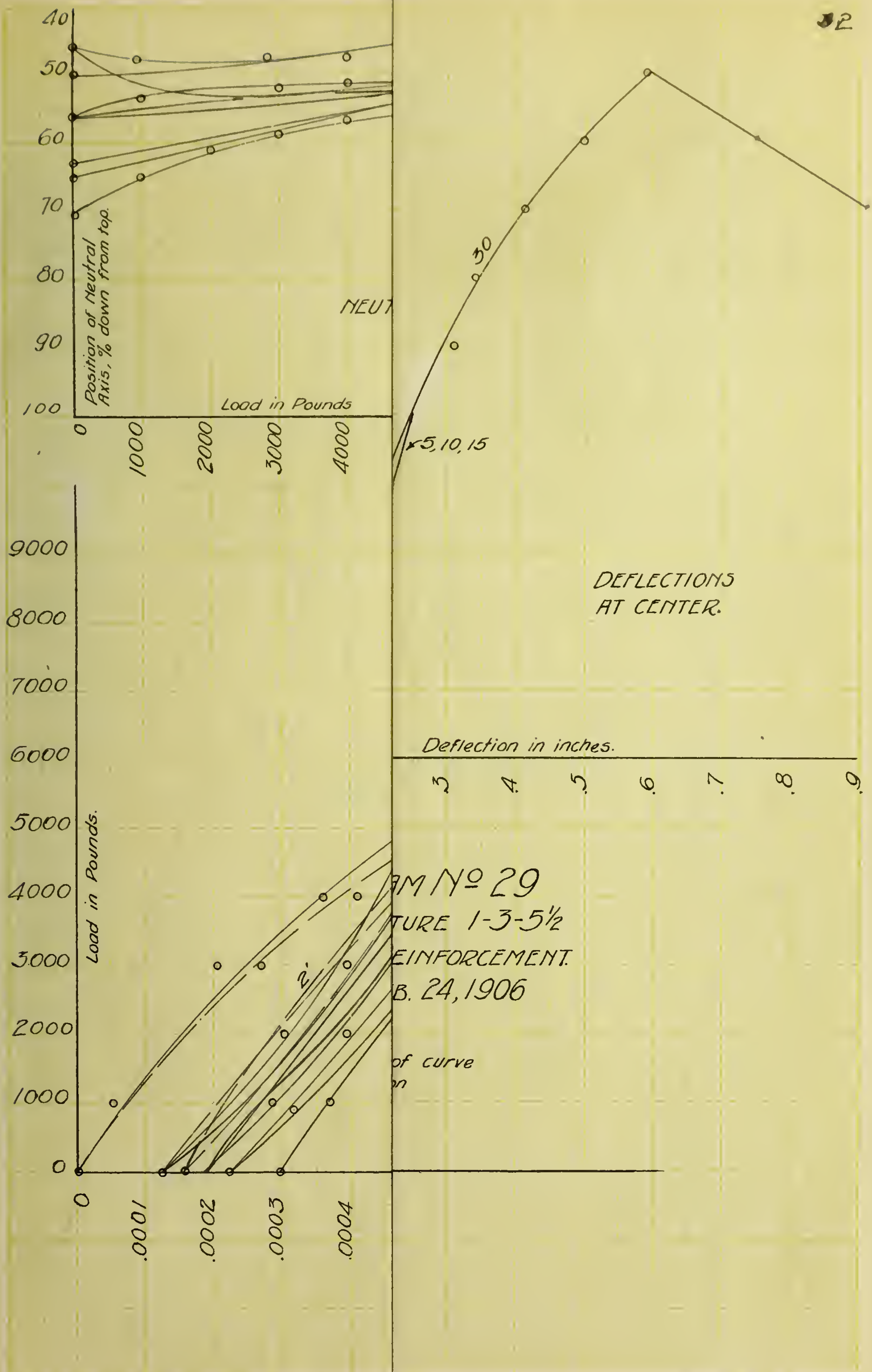
In the curves showing deflections at the center of the beams the load in pounds was taken as abscissas and the deflections at center as ordinates. To avoid confusion of lines curves were plotted for only a few series of loads. These serve very well, however, to show the increase in the permanent set and also the rate of increase of deflection throughout any series, especially in the series in which the beam was broken.

On page 37 a curve has been plotted for each beam showing how the position of the neutral axis varied for different applications

of the same load. The number of repetitions was used as abscissae and the position of the neutral axis at the full repetition load as ordinates. As in the other curves the position of the neutral axis is given in terms of the ratio of its distance down from the top of the beam to the effective depth of the beam.



Beam No. 28
Mixture 1-2-4
1% reinforcment
Ultimate Strength - 9900#
Feb. 23.- 1906.



40
50
60
70
80
90
100
Position of Neutral Axis, % down from top.
Load in Pounds
0
1000
2000
3000
4000
NEUT
30
5,10,15
DEFLECTIONS AT CENTER.
Deflection in inches.
.3
.4
.5
.6
.7
.8
.9
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Load in Pounds.
M Nº 29
TURE 1-3-5½
EINFORCEMENT.
B. 24, 1906
of curve
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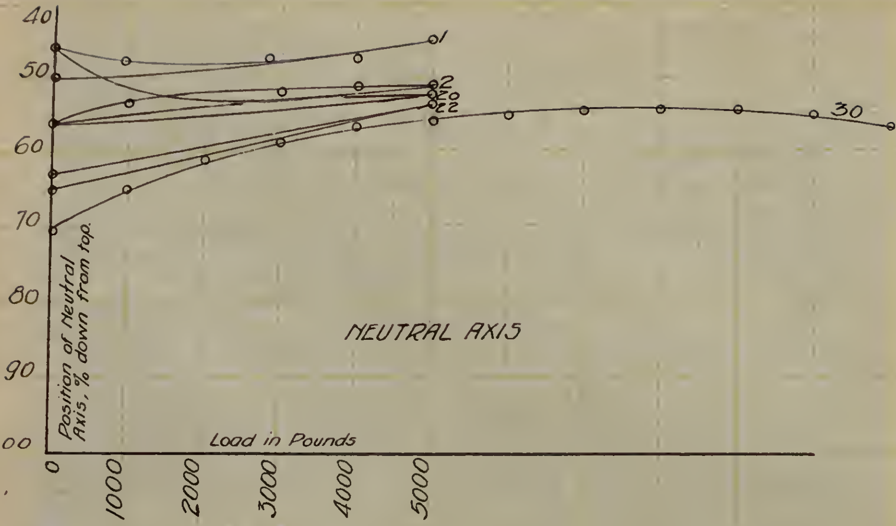
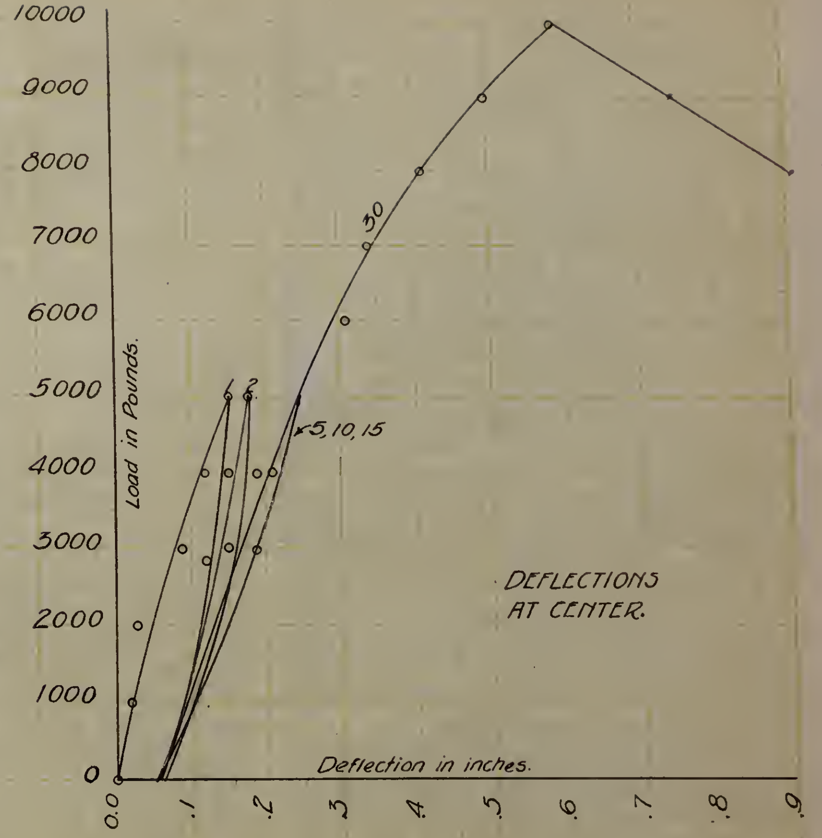
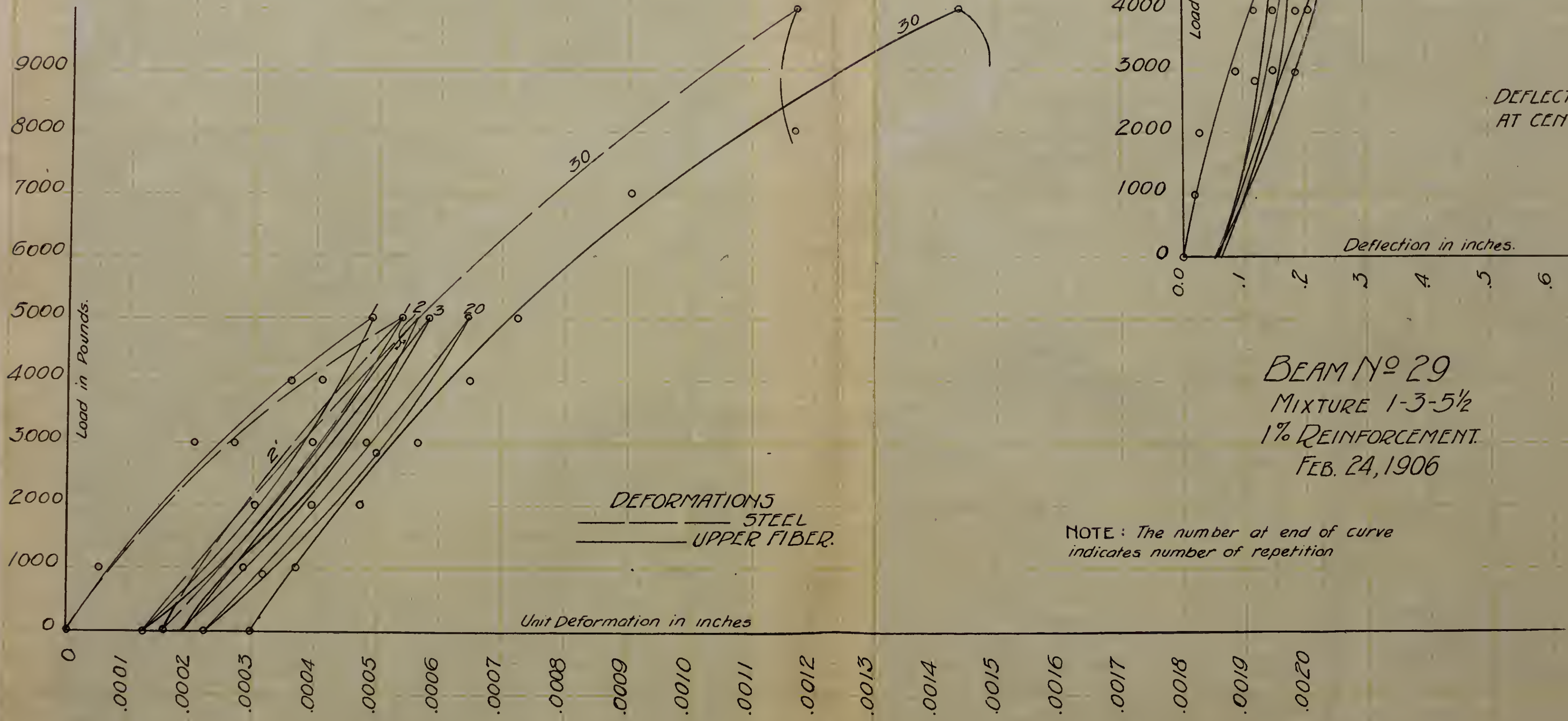
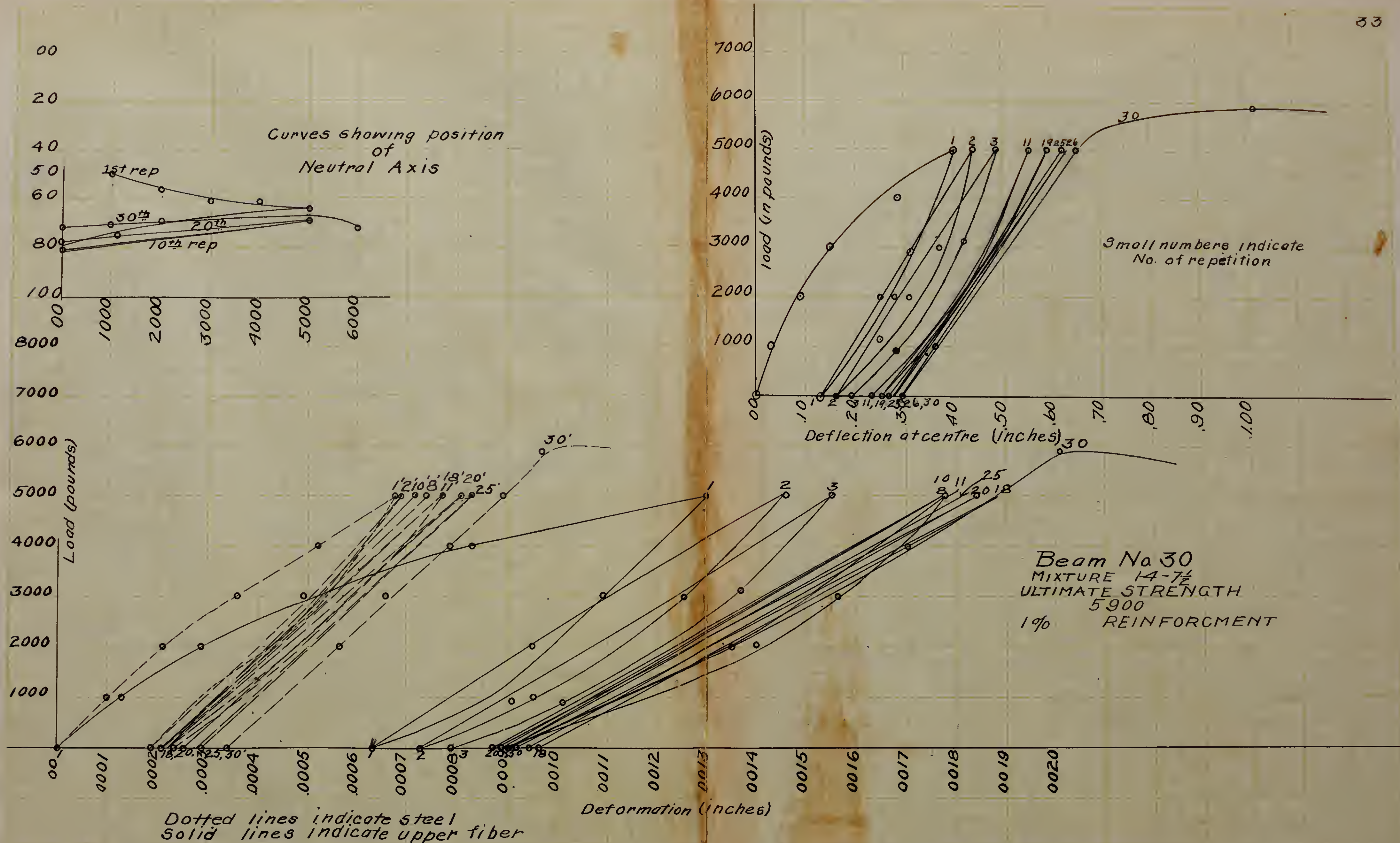






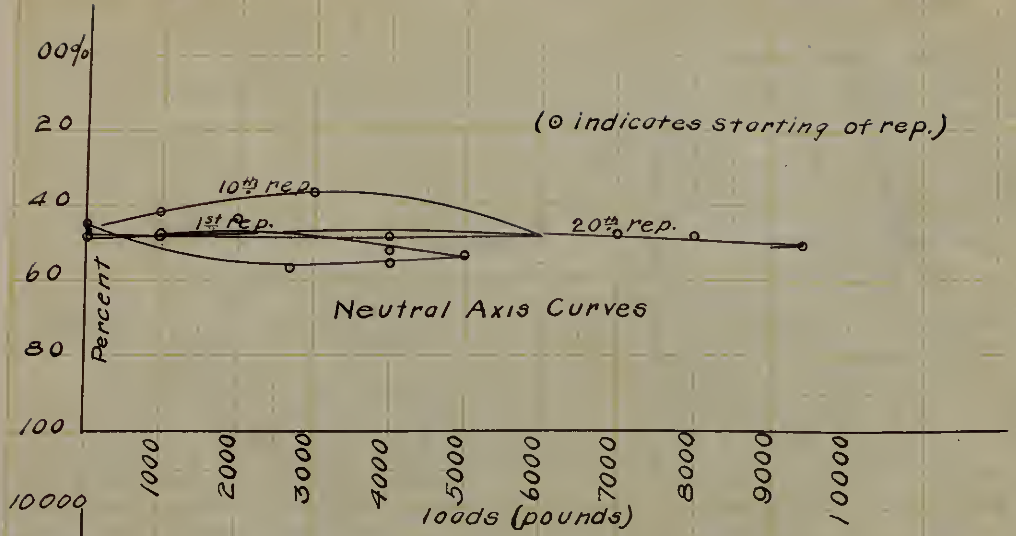
BEAM No 29
MIXTURE 1-3-5½
1% REINFORCEMENT.
FEB. 24, 1906

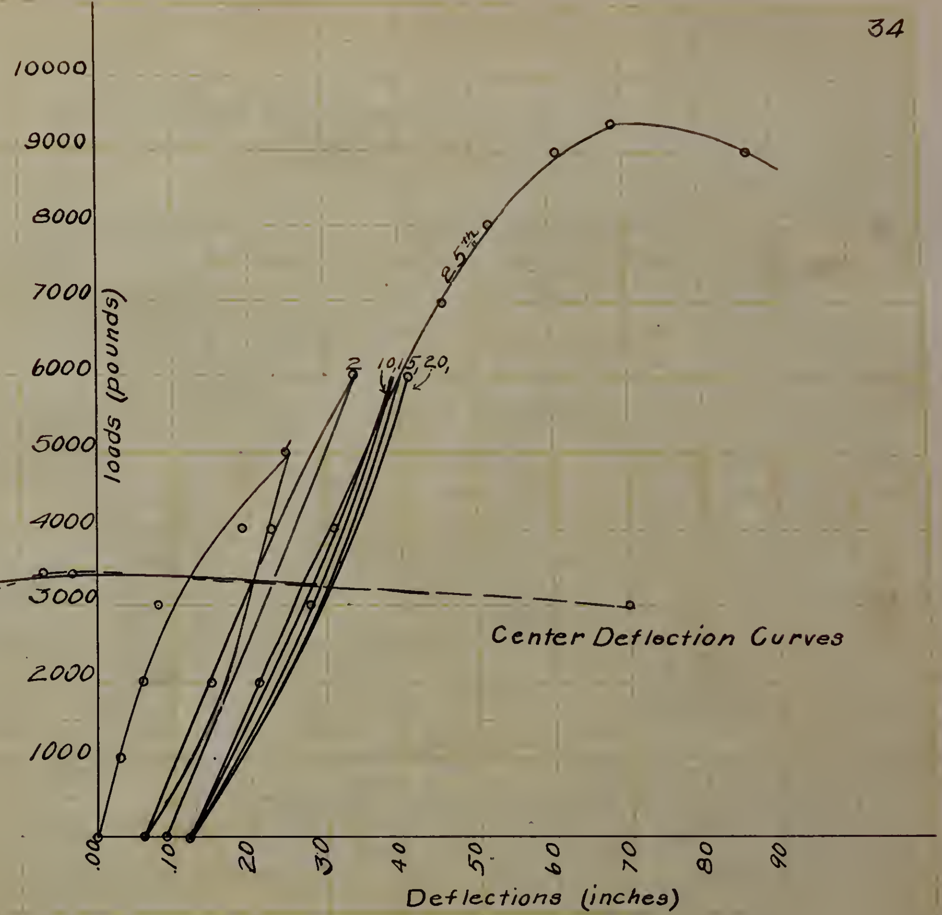
NOTE: The number at end of curve indicates number of repetition

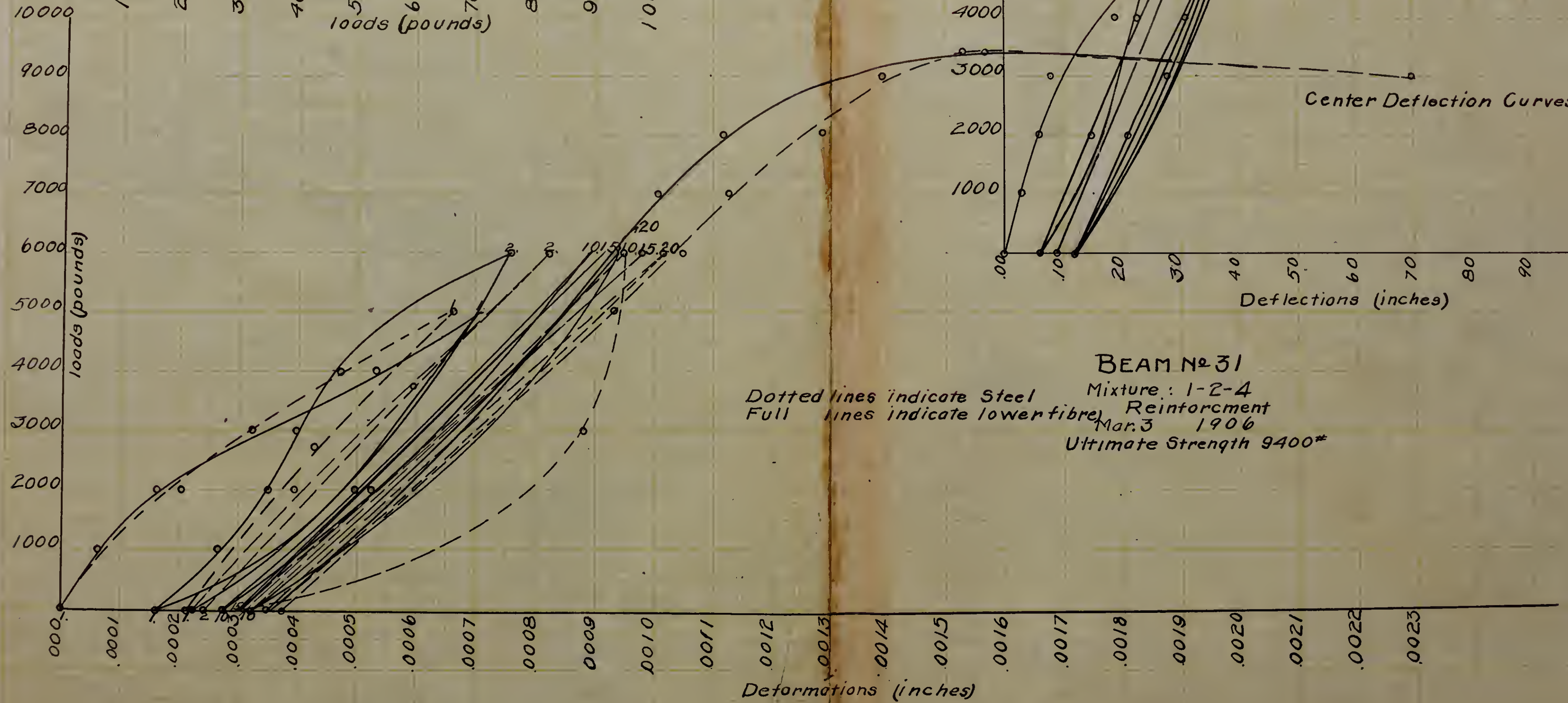


Beam No. 30
MIXTURE 1-4-7½
ULTIMATE STRENGTH
5900
1% REINFORCMENT

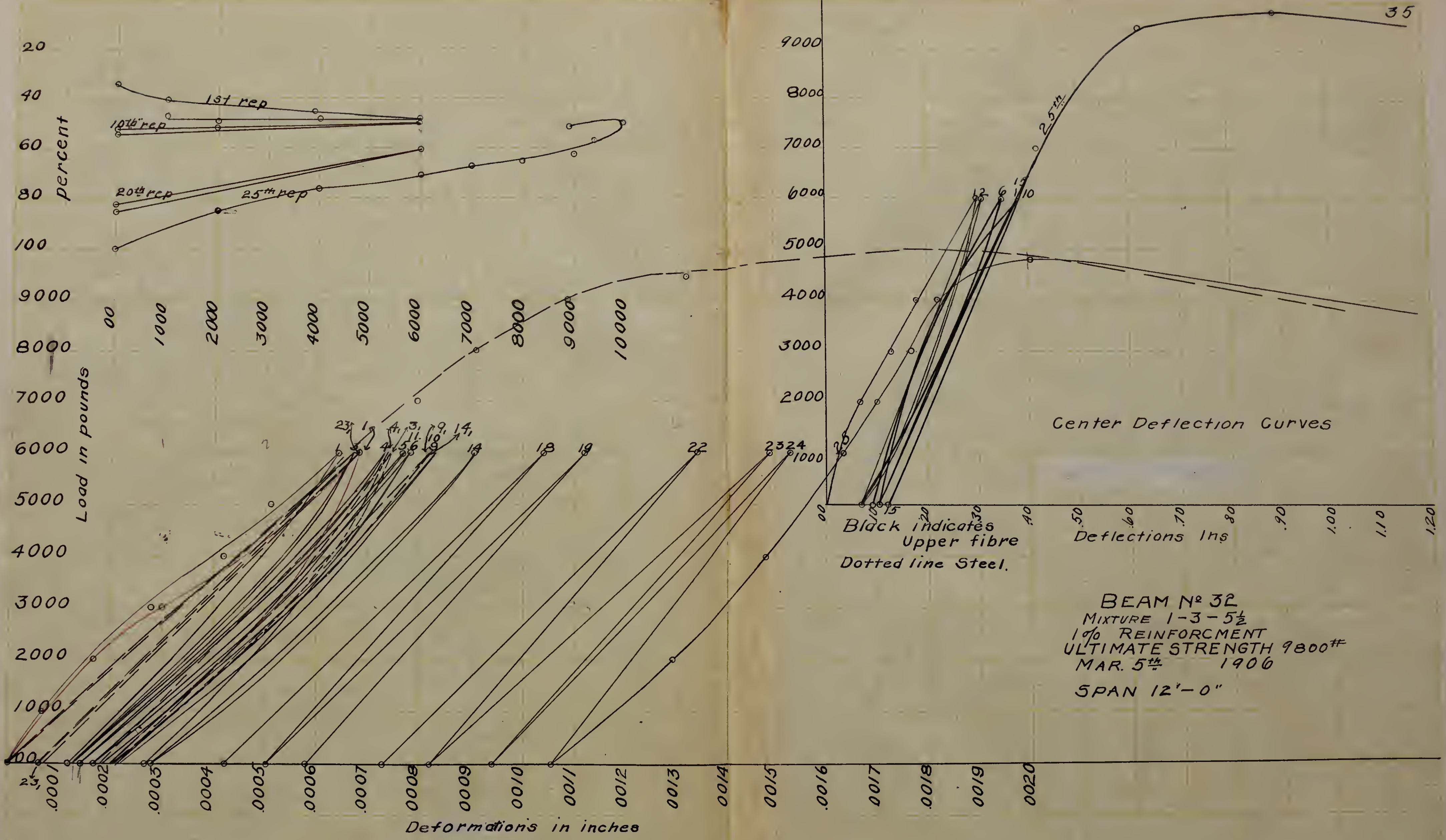
C.E.A.





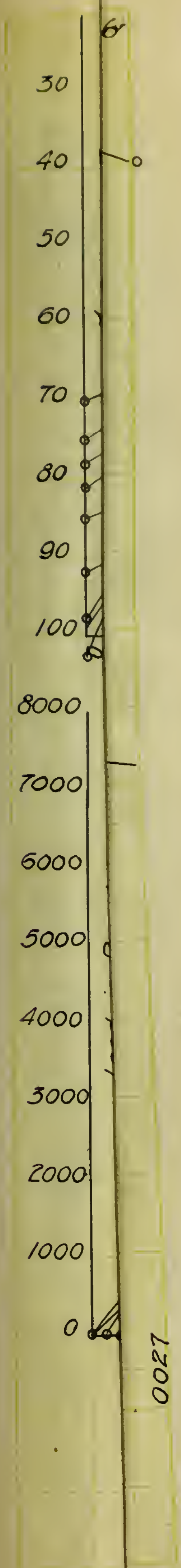


BEAM No. 31
Mixture: 1-2-4
Reinforcment
Mar. 3 1906
Ultimate Strength 9400#



percent
1st rep
10th rep
20th rep
25th rep
Load in pounds
Deformations in inches
Center Deflection Curves
Black indicates Upper fibre
Dotted line Steel.
Deflections Ins
BEAM Nº 32
MIXTURE 1-3-5½
1% REINFORCMENT
ULTIMATE STRENGTH 9800#
MAR. 5th 1906
SPAN 12'-0"

C.E.A.



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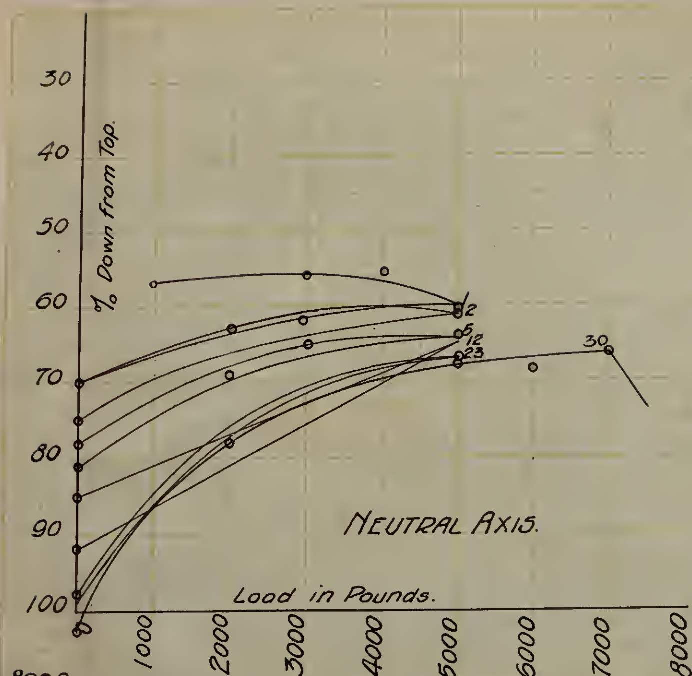
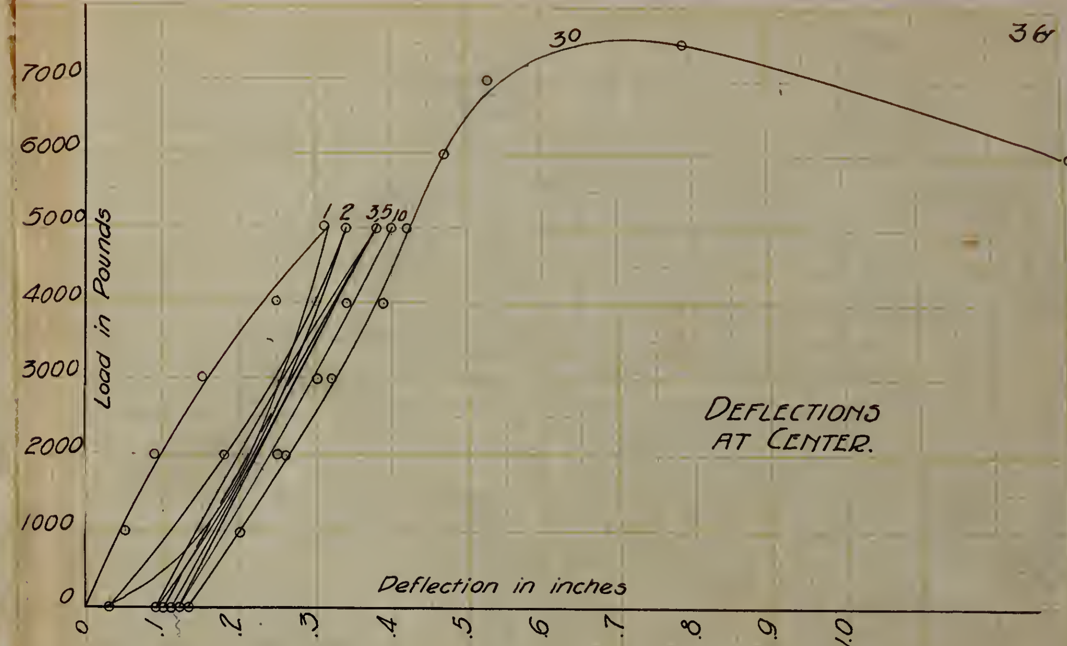
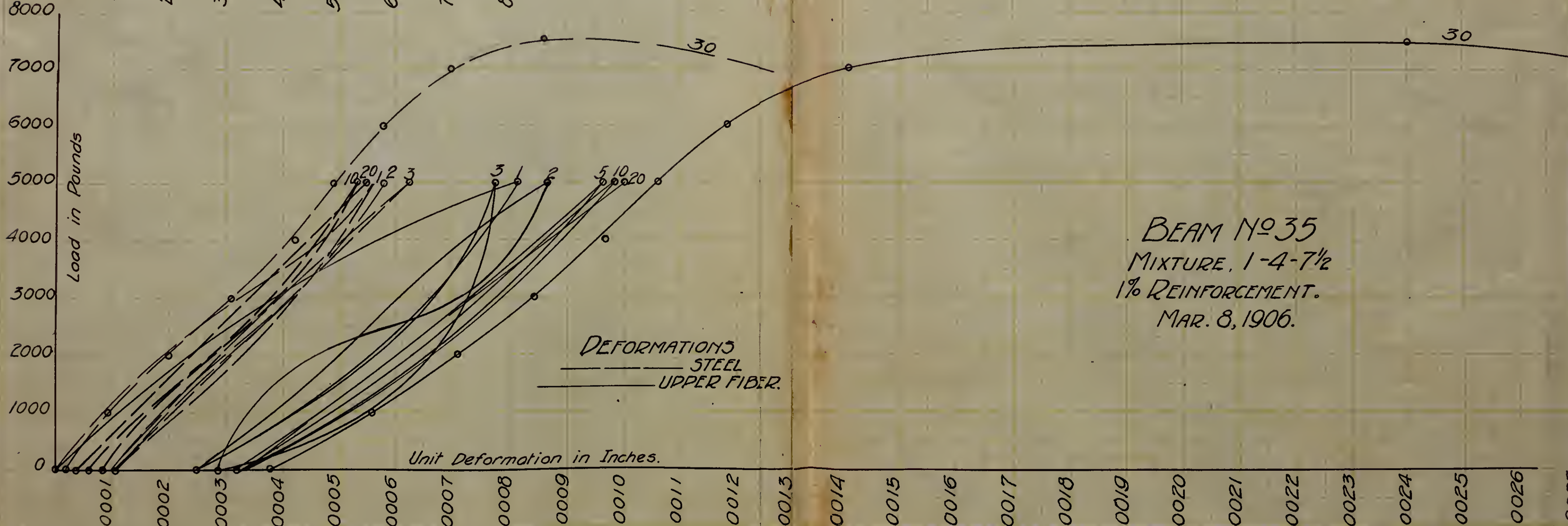
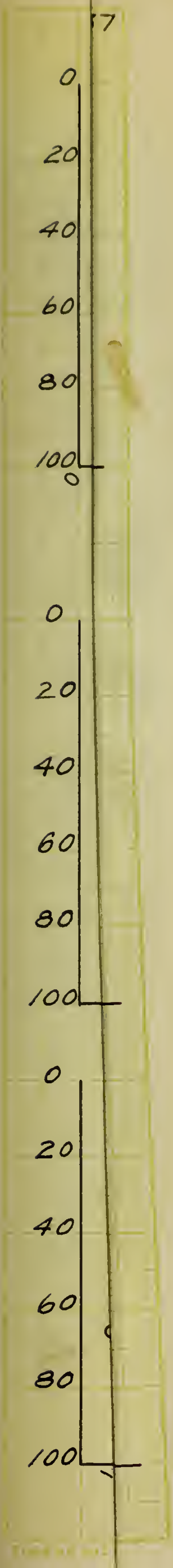






Beam No 35
Mixture, 1-4-7½
1% Reinforcement.
Mar. 8, 1906.



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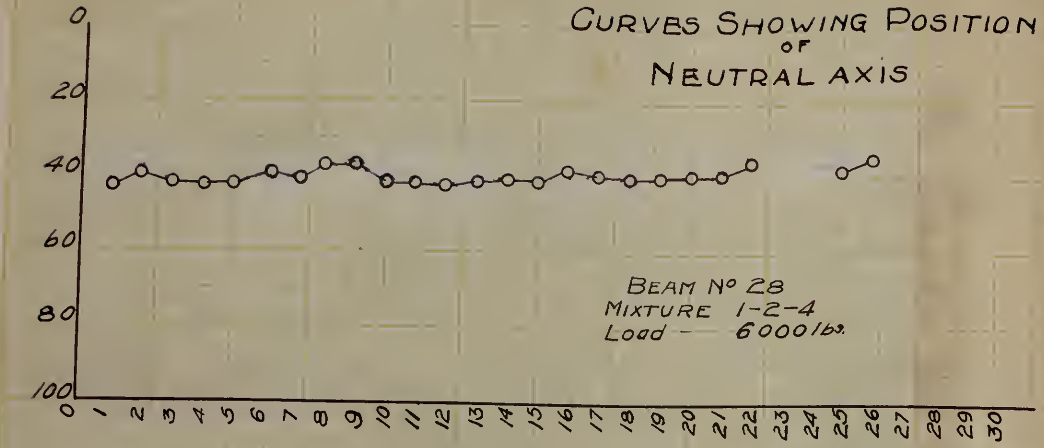
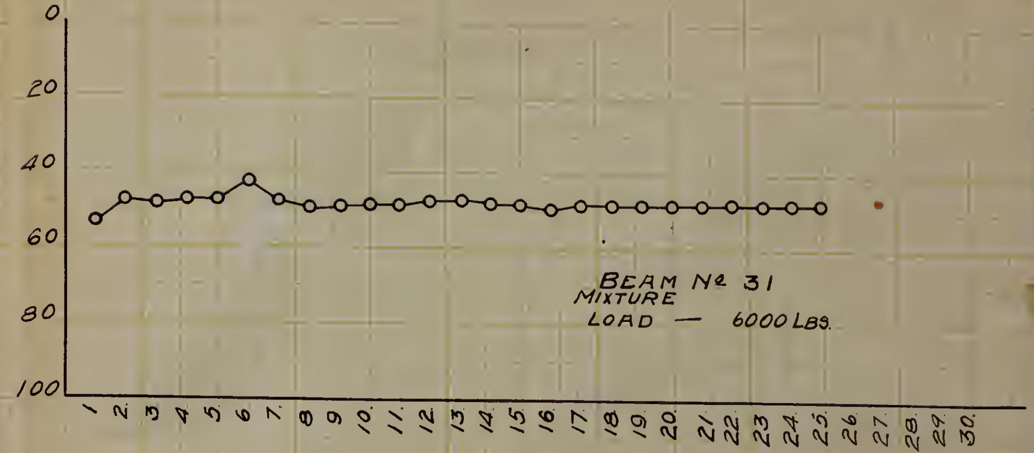
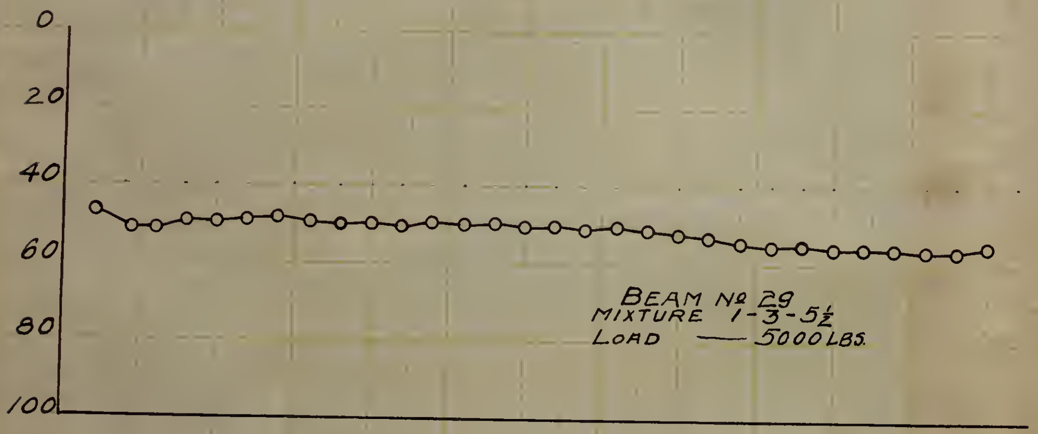
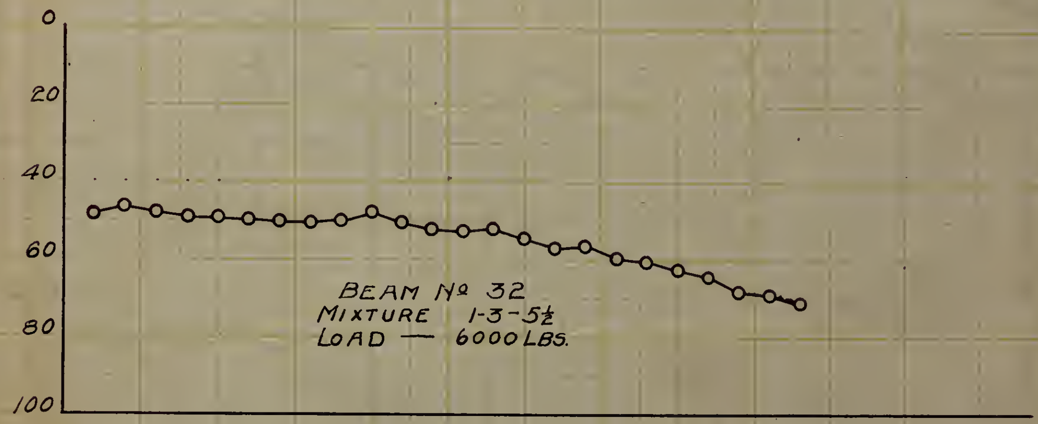
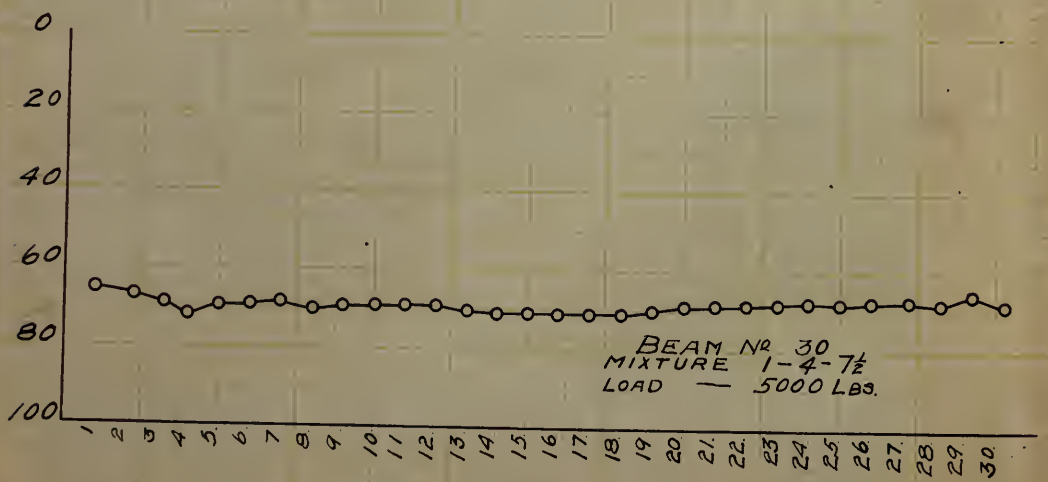
Curves Showing Position of Neutral Axis

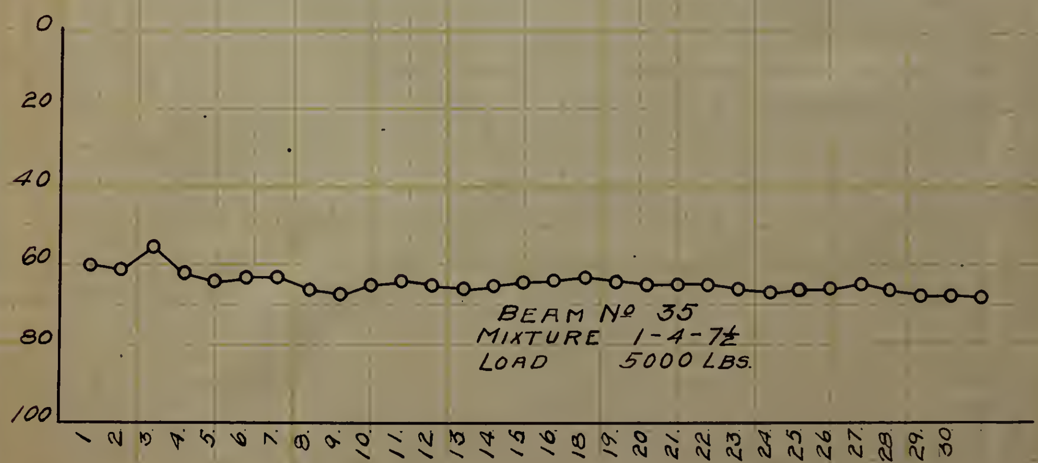












BEAM 28

APPLD LOAD LBS.	ORIGINAL READINGS EXTENSOMETERS (inches) 1	3	2	4	DEFLECTIONS AT CENTER (inches)	UNIT DEFORMATIONS UPPER FIBRE	STEEL	NEUTRAL AXIS
1 0	0	0	0	0	0.00	0	0	
1000	.0060	.0071	.0042	.0069	.03	.000063	.000059	49.0
2000	.0157	.0197	.0135	.0195	.06	152	177	46.0
3000	.0284	.0359	.0175	.0379	.12	275	353	43.0
4000	.0432	.0536	.0176	.0576	.19	396	560	42.2
5000	.0580	.0704	.0182	.0760	.25	526	708	42.5
6000	.0743	.0884	.0182	.0949	.33	670	878	43.0
3950	.0612	.0736	.0040	.0786	.28	560	717	43.6
2150	.0460	.0563	-.0140	591	.19	414	552	42.5
200	.0267	.0323	-.0374	370	.12	232	348	40.0
2 0	.0249	.0297	-.0386	314	.11	230	286	44.5
1000	.0317	.0382	-.0317	396	.15	250	376	40.0
2000	.0409	.0494	-.0224	515	.19	322	491	39.0
3000	.0501	.0604	-.0182	634	.21	394	610	39.0
4000	.0590	.0705	-.0140	745	.25	465	717	39.0
5000	.0685	.0811	-.0133	859	.29	540	823	39.5
6000	.0790	.0928	-.0119	982	.34	626	934	40.0
4050	.0661	.0784	-.0266	821	.28	524	780	40.0
1965	.0477	.0571	-.0485	583	.19	384	554	40.5
3 0	.0284	.0324	-.0707	324	.12	242	296	45.0
2000	.0452	.0525	-.0571	536	.19	370	500	42.5
4000	.0636	.0744	-.0528	777	.25	509	733	41.0
6000	.0820	.0951	-.0480	998	.34	657	940	41.0
3240	.0641	.0718	-.0742	734	.25	540	672	44.1
4 0	.0352	.0337	-.1095	329	.12	328	268	54.2
2000	.0514	.0548	-.0908	550	.15	447	490	47.5
4000	.0669	.0832	-.0693	794	.28	545	743	42.0
6000	.0841	.0972	-.0541	1110	.36	680	948	41.6
3130	.0634	.0723	-.0788	732	.28	530	676	43.9
5 0	.0332	.0341	-.1160	335	.12	297	287	50.8
2000	.0517	.0580	-.0948	576	.21	438	527	45.0
4000	.0680	.0795	-.0732	815	.29	550	764	41.8
6000	.0850	.0991	-.0550	1030	.38	712	940	42.5
3100	.0642	.0737	-.0848	753	.28	530	697	43.0
6 0	.0352	.0358	-.1200	349	.12	318	302	51.5
2000	.0528	.0583	-.0993	588	.21	450	530	46.0
4000	.0663	.0794	-.0780	821	.28	560	754	41.4
6000	.0843	.1000	-.0570	1050	.38	663	1000	39.9
3000	.0622	.0732	-.0864	751	.28	500	708	41.5
7 0	.0345	.0360	-.1210	359	.12	306	314	49.0
3000	.0624	.0709	-.0882	731	.25	513	680	43.0
6000	.0885	.1010	-.0574	1065	.38	715	1000	41.5
3900	.0640	.0749	-.0873	773	.27	516	726	41.4
0	.0332	.0364	-.1229	369	.12	.000283	.000337	45.6

APPLD LOAD LBS.	ORIGINAL READINGS EXTENSOMETERS (inches) 1	3	2	4	DEFLECTIONS AT CENTER (inches)	UNIT DEFORMATIONS UPPER FIBRE	STEEL	NEUTRAL AXIS
8 0	.0364	.0364	-1229	369	.12	.000283	.000337	45.6
3000	584	714	-899	741	25	456	698	39.0
6000	849	1016	-592	1079	38	657	1035	38.8
3000	781	950	-691	999	34	600	963	38.4
9 0	291	378	-1258	375	12	285	340	45.5
3000	567	719	-922	755	27	524	698	43.0
6000	835	1023	-590	1098	38	624	1075	37.0
2830	588	738	-923	777	28	528	753	41.8
10 0	288	375	-1267	389	13	270	374	42.0
3000	676	722	-939	769	26	593	698	46.0
6000	844	1026	-626	1099	38	760	1040	42.0
3000	605	757	-922	794	28	550	760	42.0
11 0	294	381	-1277	396	13	280	367	43.0
3000	585	732	-940	770	26	540	715	43.0
6000	845	1032	-642	1111	39	766	1040	42.2
3000	619	765	-933	807	29	565	752	43.0
12 0	317	381	-1289	401	13	287	370	44.0
1000	389	493	-1194	514	16	364	478	43.0
2000	499	625	-1065	659	21	458	612	42.9
3000	593	737	-953	782	26	545	728	42.7
4255	707	868	-820	929	32	640	870	42.5
5000	778	950	-734	1021	34	705	950	42.2
6000	861	1042	-639	1125	39	775	1050	42.1
3900	769	871	-808	929	31	685	850	44.5
1920	523	641	-1044	670	25	480	710	44.0
13 0	320	387	-1270	409	14	293	375	44.0
3000	605	742	-938	790	28	550	733	43.0
6000	873	1045	-625	1133	40	778	1065	42.0
2850	626	767	-920	81.1	28	570	752	43.0
14 0	323	396	-1268	412	14	300	383	44.2
3000	607	663	-930	797	28	497	760	39.2
6000	880	969	-61.5	142	40	730	1092	40.0
2950	630	692	-92.7	821	28	518	784	40.0
15 0	269	312	-1280	419	15	205	422	33.0
3000	619	687	-942	809	28	515	770	40.0
6000	882	989	-631	1148	40	740	1100	40.5
2940	629	714	-930	842	28	520	806	39.1
16 0	332	332	-1279	440	15	247	520	37.0
6000	948	1006	-618	1180	41	713	1130	38.5
17 0	359	338	-1277	452	15	272	420	39.2
6000	922	1011	-619	1191	41	760	1027	40.0
18 0	370	348	-1276	468	15	273	455	37.8
6000	932	1025	-612	1212	42	768	1150	40.0
0	401	356	-1274	489	15	000289	000474	38.0

BEAM 28

APPLD LOAD LBS.	ORIGINAL READINGS EXTENSOMETERS (inches) 1	3	2	4	DEFLECTIONS AT CENTER (inches)	UNIT DEFORMATIONS UPPER FIBRE	STEEL	NEUTRAL AXIS
19 0	0401	.0356	-.1274	0489	15	000289	.000474	38.0
6000	969	1033	-604	1238	41	788	1180	40.0
20 0	404	361	-1270	510	15	283	500	36.0
6000	977	1037	-604	1258	41	788	1200	39.5
21 0	409	370	-1288	533	15	283	528	35.0
6000	972	1038	619	1263	41	780	1200	39.2
22 0	411	38.8	1287	558	15	286	554	34.0
2000	600	632	1062	817	23	463	797	37.0
4000	802	867	820	1080	34	640	1035	38.0
6000	980	1062	613	1370	41	760	1340	36.0
2600	754	754	965	693	28	700	573	55.0
23 0	414	402	1291	587	15	285	590	33.0
6000								
24 0								
6000								
25 0								
6000	1090	1124	-597	1415	42	850	1360	38.2
26 0	419	440	-1289	671	15	277	690	29.0
1000	507	558	-1187	793	19	360	806	31.0
2000	621	695	-1053	944	25	463	946	33.0
3000	726	820	-.0932	1080	28	550	1075	34.0
4000	819	925	-.0821	1200	33	618	1100	34.2
5000	905	.1028	-.0707	1322	38	704	1300	35.0
6000	997	.1116	-.0616	1424	42	778	1400	35.8
7000	1082	.1219	-.0517	1537	45	857	1500	36.1
8000	1209	.1359	-.0386	1684	51	966	1635	37.1
9000	1376	.1551	-.0241	1861	56	1125	1790	38.5
9900	1583	.~~1917~~	-.0060	2380	66	1280	.002330	35.5
9000	1601	—	—	—	107	—	—	—
8930	1601	—	—	—	147	—	—	—

BEAM 29.

APPLD LOAD LBS.	ORIGINAL READINGS EXTENSOMETERS (inches) 1	3	2	4	DEFLECTIONS AT CENTER (inches)	UNIT DEFORMATIONS UPPER FIBRE	STEEL	NEUTRAL AXIS
1 0	0	0	0	0	0.00	0.000000	0.000000	
1000	.0068	60	43	61	0.02	054	54	50.0
2000	166	162	138	170	3	146	150	49.0
3000	281	285	264	256	9	272	206	47.0
4000	409	423	406	458	12	361	410	46.9
5000	521	562	548	607	15	484	540	47.0
2850	380	425	395	454	12	369	404	47.6
950	219	242	215	255	9	210	227	48.0
2 0	119	153	114	171	6	128	157	46.0
1000	192	254	182	240	9	248	200	53.5
2000	293	365	286	351	12	330	296	52.9
3000	357	447	365.	437	14	405	375	52.0
4000	431	540	457	531	15	485	457	51.5
5000	513	629	545	624	19	563	538	51.4
2800	375	479	385	463	16	436	393	52.5
950	202	288	196	276	9	263	234	53.0
3 0	104	201	98	178	6	188	143	56.0
1000	249	274	173	184	9	286	217	71.0
2000	275	371	268	350	12	340	295	54.0
3000	347	471	367	456	15	429	387	52.7
4000	391	563	459	552	19	510	470	52.0
5000	441	649	546	644	22	581	553	51.5
3000	300	503	397	496	19	456	425	51.8
900	106	289	193	281	9	261	242	52.1
4 0	008	200	96	195	6	182	164	52.0
2000	178	375	278	389	12	331	340	49.5
3000	264	476	379	484	16	423	418	50.5
5000	375	650	554	669	22	574	582	49.7
3000	236	497	395	509	18	440	440	50.0
5 0	-.0054	200	91	202	6	179	175	50.0
3000	212	477	363	492	19	420	438	49.0
5000	367	661	545	685	25	582	600	49.5
3000	219	501	383	466	19	466	381	55.0
6 0	-.0073	198	75	209	6	172	180	49.0
3000	199	485	349	501	18	426	438	49.7
5000	355	661	524	685	24	581	600	49.2
3020	211	504	360	519	19	450	440	51.0
7 0	- 81	199	52	208	6	175	180	49.6
3000	181	490	332	505	19	432	440	50.0
5000	343	666	508	688	25	580	603	49.1
3000	194	511	348	524	19	447	448	50.0
8 0	- 105	199	31	208	6	173	180	49.8
3000	173	494	320	509	19	435	445	49.9
5000	318	670	498	692	25	590	608	49.5

BEAM 29 (continued)

APPLD LOAD LBS.	ORIGINAL READINGS EXTENSOMETERS (inches) 1	3	2	4	DEFLECTIONS AT CENTER (inches)	UNIT DEFORMATIONS UPPER FIBRE	STEEL	NEUTRAL AXIS
3000	0.0156	0.0513	0.0327	0.0523	19	.000455	.000455	500
9 0	-139	203	0013	209	6	179	179	510
3000	124	488	297	500	19	430	437	500
5000	289	669	480	689	25	590	600	500
2950	137	507	312	514	19	452	445	510
10 0	-151	204	002	206	6	179	178	500
3000	115	497	292	508	19	433	437	500
5000	277	677	476	697	25	614	607	498
2800	113	501	297	509	19	450	439	509
11 0	-164	205	-0007	213	6	180	182	500
2000	023	395	186	401	14	354	345	510
3000	111	503	290	514	19	450	446	500
5000	277	689	472	700	25	611	607	505
2850	112	507	289	515	20	452	444	509
900	-070	302	87	303	10	270	260	510
12 0	-169	208	-0019	211	6	184	180	500
5000	278	682	459	703	25	600	616	497
13 0	-179	210	-0029	212	6	187	180	510
5000	274	688	452	706	25	608	613	500
14 0	-177	212	-0038	212	6	189	178	512
5000	267	683	438	700	25	604	609	499
15 0	-181	214	-049	210	6	193	174	530
5000	275	698	424	706	25	625	613	505
16 0	-175	216	-068	210	6	195	176	530
5000	278	691	414	704	25	614	609	503
17 0	-170	216	-073	212	6	195	178	520
5000	290	704	418	717	27	625	623	513
18 0	-168	221	-079	213	6	202	178	530
5000	290	701	404	711	25	625	615	506
19 0	-164	221	-087	214	6	201	178	530
5000	299	718	387	713	27	643	595	512
20 0	-160	237	-107	215	6	220	174	560
2000	030	431	084	410	15	396	341	540
3000	125	537	188	520	19	492	439	530
5000	295	717	373	700	25	648	591	523
2850	132	544	195	521	19	498	439	531
900	-057	335	-016	302	9	316	243	570
21 0	-157	242	-121	219	6	225	176	560
5000	307	736	361	705	25	670	590	532
22 0	-150	253	-137	201	6	252	146	630
5000	310	743	344	697	25	688	580	542
23 0	-149	260	-148	195	6	261	141	650
5000	309	748	336	694	25	697	554	555
24 0	-149	264	-159	190	6	.000268	.000125	680

BEAM 29 (continued)

APPLD LOAD LBS.	ORIGINAL READINGS EXTENSOMETERS (inches) 1	3	2	4	DEFLECTIONS AT CENTER (inches)	UNIT DEFORMATIONS UPPER FIBRE	STEEL	NEUTRAL AXIS
24 0	-.0149	.0264	-.0159	.0190	.06	.000268	.000125	68.0
5000	306	750	324	689	.25	702	562	55.1
25 0	-156	268	-170	191	.06	272	127	67.5
5000	304	762	317	694	.26	711	562	56.0
26 0	-160	273	-182	190	.06	284	125	69.0
5000	302	761	309	695	.25	713	564	56.0
27 0	-168	280	-193	191	.06	289	125	70.0
5000	295	774	298	698	.25	723	568	56.0
28 0	-167	280	-208	191	.06	289	125	69.9
5000	298	773	286	694	.27	725	558	56.5
29 0	-167	281	-218	197	.06	291	127	69.4
2000	033	483	-20	392	.15	473	295	61.9
3000	128	590	87	504	.19	570	393	59.2
5000	297	775	269	695	.27	730	556	56.7
3000	125	590	82	496	.19	572	384	59.9
300	-130	321	-185	224	09	330	146	69.0
30 0	-163	284	-227	190	.06	296	123	70.6
1000	-078	371	-140	280	.09	370	198	65.2
2000	036	487	-25	399	.15	473	303	61.0
3000	126	590	+77	506	.19	566	395	59.0
4000	215	687	173	608	.21	650	485	57.0
5000	296	775	263	700	.25	725	570	56.0
6000	380	868	355	795	.31	807	634	55.3
7000	484	982	470	909	.34	907	750	54.7
8000	619	1144	625	1064	.41	1058	875	54.4
9000	798	1333	790	1235	.50	1234	1008	54.7
10000	1021	1554	990	1430	.59	1440	1172	55.1
9000	1098	1580	950	1401	.75	1490	1126	56.9
8000	~	.1474	.0910	.1401	.91	1350	1170	53.3

BEAM 30J

APPLD LOAD LBS.	ORIGINAL READINGS EXTENSOMETERS (inches) 1	3	2	4	DEFLECTIONS AT CENTER (inches)	UNIT DEFORMATIONS UPPER FIBRE	STEEL	NEUTRAL AXIS
1 0	0	0	0	0	.69	0.00000	0.00000	
1000	.0118	.0122	.0102	.0107	.72	13	10	56.5
2000	.0292	.0305	.0256	.0268	.78	29	21	57.2
3000	.0531	.0557	.0451	0469	.84	53	36	59.5
4000	.0824	.0875	.0670	.0698	.98	83	52	61.8
5000	.1238	.1332	.0944	.0980	1.09	130	68	65.4
2950	.0983	.1143	.0761	.0784	1.00	108	53	67.0
1150	.0805	.0861	.0513	.0522	.94	89	30	75.0
2 0	.0553	.0606	.0323	.0342	.82	63	19	78.1
2000	.0874	.0944	.0582	.0612	.94	95	41	72.0
3000	.1029	.1115	.0720	.0760	1.00	109	49	69.5
5000	.1345	.1480	.0989	.1049	1.13	146	69	67.0
2950	.1152	.1259	.0792	.0837	1.07	125	52	71.0
980	.0835	.0934	.0511	.0551	.94	95	33	76.2
3 0	.0605	.0701	.0342	.0381	.85	72	20	80.0
2000	.0956	.1068	.0618	.0670	.97	107	42	73.6
3000	.1109	.1235	.0752	.0813	1.03	122	50	71.2
5000	.1390	.1600	.1003	.1084	1.15	155	69	69.0
3100	.1230	.1391	.0832	.0900	1.08	137	54	71.7
930	.0889	.1011	.0518	.0679	.94	101	39	74.1
4 0	.0652	.0774	.0350	.0409	.88	79	19	82.0
3000	.1170	.1324	.0775	.0856	1.06	131	50	72.0
5000	.1458	.1643	.01027	.1129	1.17	153	73	68.5
2650	.1210	.1373	.0788	.0870	1.06	137	50	73.2
5 0	.0671	.0809	.0358	.0434	.88	81	18	81.5
3000	.1209	.1384	.0788	.0888	1.06	137	51	72.9
5000	.1500	.1694	.1042	.1159	1.18	167	72	69.5
3000	.1279	.1474	.0835	.0940	1.09	145	54	73.0
6 0	.0682	.0847	.0359	.0451	.88	85	18	82.4
5000	.1517	.1730	.1052	.1186	1.18	168	73	69.6
7 0	.0686	.0878	.0374	.0480	.91	86	21	81.6
5000	.1531	.1723	.1067	.1214	1.21	176	74	68.5
8 0	.0693	.0895	.0375	.0489	.91	87	21	80.9
5000	.1593	.1792	.1072	.1229	1.21	176	74	70.2
9 0	.0697	.0915	.0377	.0502	.91	89	21	81.0
5000	.1546	.1818	.1075	.1242	1.21	174	76	69.5
10 0	.0698	.0922	.0375	.0515	.91	89	22	80.5
5000	.1570	.1842	.1080	.1265	1.23	176	72	69.5
11 0	.0698	.0944	.0373	.0525	.92	90	22	80.6
2000	.1111	.1388	.0687	.0858	1.06	135	39	77.8
3000	.1274	.1574	.0832	.1012	1.12	150	57	72.6
5000	.1551	.1866	.1082	.1277	1.24	177	77	69.5
2800	.1294	.1606	.0847	.1020	1.12	153	57	73.0
0	.0622	.0968	.0373	.0534	.94	0.00087	0.00023	78.5

APPLD LOAD LBS.	ORIGINAL READINGS EXTENSOMETERS (inches) 1	3	2	4	DEFLECTIONS AT CENTER (inches)	UNIT DEFORMATIONS UPPER FIBRE	STEEL	NEUTRAL AXIS
12 0	.0622	.0968	.0373	.0534	.94	0.00087	0.00023	78.5
5000	.1551	1903	1085	1289	1.25	179	77	69.5
13 0	669	991	366	544	.92	91	22	81.0
5000	1556	1922	1075	1285	1.25	179	74	70.5
14 0	678	1013	362	536	.94	92	21	81.5
5000	1580	1954	1080	1294	1.26	184	75	71.0
15 0	687	1025	357	540	.94	94	20	82.7
5000	1590	1974	1087	1305	1.26	185	75	71.0
16 0	689	1043	361	549	.91	96	20	82.5
5000	1599	1984	1085	1309	1.26	188	75	71.2
17 0	697	1055	356	552	.94	97	20	83.0
5000	1595	2000	1086	1319	1.27	189	76	71.0
18 0	689	1065	358	560	.95	91	22	79.6
5000	1585	2014	1091	1330	1.28	188	77	70.9
19 0	678	1070	360	567	.96	96	21	82.0
2000	1119	1555	703	926	1.00	143	46	75.5
3000	1285	1725	840	1084	1.17	159	58	73.2
5000	1539	2005	185	1333	1.28	183	78	70.0
2800	1287	1742	845	1074	1.17	161	57	73.6
20 0	646	1074	357	.572	.97	94	21	81.2
5000	1451	2018	1085	1336	1.29	179	85	69.0
21 0	543	1074	360	580	.97	88	25	77.9
5000	1451	2030	1092	1352	1.29	179	81	68.6
22 0	531	1079	360	584	.97	87	25	77.4
5000	1450	2035	1095	1359	1.29	179	82	68.5
23 0	529	1083	363	591	.97	86	27	76.0
5000	1456	2048	1103	1371	1.31	180	83	68.3
24 0	532	1098	371	602	.98	88	27	76.1
5000	1460	2059	1112	1384	1.31	181	84	68.0
25 0	535	1100	376	614	.98	88	28	75.6
5000	1467	2064	1114	1390	1.31	181	84	68.1
26 0	540	1107	380	624	.98	89	29	75.4
5000	1470	2078	1122	1400	1.32	182	85	67.9
27 0	544	1116	385	630	1.00	89	29	75.2
5000	1478	2085	1125	1409	1.32	183	85	67.8
28 0	550	1124	390	637	1.00	90	30	75.0
5000	1491	2098	1132	1414	1.34	184	82	68.0
29 0	561	1134	395	647	1.00	90	30	74.9
2000	999	1575	795	1055	1.15	131	63	67.2
3000	1180	1770	937	1209	1.21	151	72	66.6
5000	1479	2076	1185	1468	1.37	181	93	65.6
2990	1260	1851	966	1238	1.25	160	73	68.0
0	550	1123	434	686	1.00	0.00090	0.00034	72.4

BEAM 30 (Concluded)

APPLD LOAD LBS.	ORIGINAL READINGS EXTENSOMETERS (inches) 1	3	2	4	DEFLECTIONS AT CENTER (inches)	UNIT DEFORMATIONS UPPER FIBRE	STEEL	NEUTRAL AXIS
30 0	.0550	.1123	.0434	.0686	1.00	0.00090	0.00034	72.4
1000	799	1389	591	850	1.07	114	45	71.8
2000	1030	1618	755	1025	1.15	140	56	70.9
3000	1208	1804	899	1180	1.21	156	66	69.6
4000	1358	1953	1030	1316	1.28	170	79	68.0
5000	1500	2100	1156	1447	1.34	183	89	68.0
5900	1602	2238	1250	1262	1.69	0.00201	0.00077	72.0

BEAM 31

APPLD LOAD LBS.	ORIGINAL READINGS EXTENSOMETERS (inches) 1	3	2	4	DEFLECTIONS AT CENTER (inches)	UNIT DEFORMATIONS UPPER FIBRE	STEEL	NEUTRAL AXIS
1 0	0000	0000	0000	0000	0.00	.000000	.000000	
1000	.084	.067	.070	91	.03	.000062	72	480
2000	208	181	185	226	.06	161	207	440
3000	347	426	336	395	.08	395	321	550
4000	499	660	497	564	.19	532	473	625
5000	652	890	657	733	.25	710	614	535
2700	470	687	423	531	.19	540	428	560
950	289	474	280	338	.12	358	268	578
2 0	184	216	173	230	.06	162	211	450
2000	384	435	321	442	.15	350	395	470
4000	580	647	571	659	.23	460	610	430
6000	822	930	790	930	.34	760	824	480
3850	660	745	650	747	.25	633	597	514
1000	354	416	280	400	.15	365	268	580
3 0	227	290	160	273	.09	223	246	480
2000	439	523	377	503	.19	420	443	490
4000	649	755	595	740	.27	608	653	485
6000	847	998	747	974	.34	804	960	484
4150	703	834	580	810	.28	670	715	485
1000	351	451	210	419	.15	.352	367	480
4 0	219	315	.083	296	.11	227	268	465
4000	671	814	565	789	.28	664	634	514
6000	851	1038	746	1011	.38	813	893	475
3000	580	745	446	703	.25	575	624	480
5 0	219	353	.082	314	.12	245	284	469
4000	664	835	558	807	.28	643	717	474
6000	855	1050	700	1023	.38	822	910	475
3000	585	763	456	617	.27	626	503	555
6 0	210	357	145	311	.12	241	285	462
4000	656	850	563	811	.28	650	723	474
6000	855	1073	704	1137	.38	780	1060	425
3000	580	772	455	718	.27	585	635	480
7 0	213	397	120	324	.12	264	288	480
4100	674	911	590	835	.30	678	740	479
6000	851	1116	735	1044	.38	850	926	479
2700	650	906	504	816	.30	677	718	485
8 0	202	430	.050	332	.11	276	294	490
4000	663	930	515	836	.28	694	739	484
6000	862	1160	630	1061	.39	880	937	495
3000	675	847	387	735	.26	690	617	530
9 0	190	439	-042	334	.12	271	298	480
4000	659	956	453	850	.31	715	715	502
6000	850	1170	662	1069	.38	882	930	488
2500	.0501	.0800	.0280	.0674	.25	572	585	496

BEAM 31 (continued)

APPLD LOAD LBS.	ORIGINAL READINGS EXTENSOMETERS (inches) 1	3	2	4	DEFLECTIONS AT CENTER (inches)	UNIT DEFORMATIONS UPPER FIBRE	STEEL	NEUTRAL AXIS
10 0	.0179	.0446	-.0046	0335	.12	.000271	.000300	48.0
2000	420	720	196	596	.21	499	525	49.0
4000	650	970	446	854	.31	705	754	48.4
6000	851	1200	664	1079	.39	895	951	48.5
3000	552	890	340	750	.28	632	882	3 68
11 0	163	472	- 046	342	.12	271	305	47.0
6000	840	1220	650	1084	.40	898	953	48.6
12 0	154	484	- 066	344	.00	277	307	48.5
6000	823	1225	620	1090	.39	885	967	47.9
13 0	147	495	- 094	349	.12	277	310	48.0
6000	819	1240	580	1095	.40	892	970	47.9
14 0	150	514	- 134	355	.11	289	312	48.5
6000	818	1260	565	1097	.40	900	968	48.3
15 0	157	530	- 140	360	.12	300	314	49.0
6000	827	1275	535	1108	.40	916	980	48.5
16 0	157	540	- 157	365	.12	304	321	49.0
6000	833	1287	552	1115	.38	922	984	49.5
17 0	153	545	- 170	370	.12	304	328	48.0
6000	829	1290	540	1118	.37	918	986	48.2
18 0	162	554	- 179	375	.12	314	330	49.0
6000	835	1300	527	1124	.37	928	988	48.5
19 0	162	564	- 190	380	.12	317	336	49.0
6000	844	1317	506	1134	.38	940	1000	48.5
20 0	161	580	194	390	.12	321	346	48.5
2000	414	850	- 80	650	.21	557	565	49.7
6000	845	1330	210	1147	.41	943	1016	48.2
2900	539	1040	- 119	796	.28	703	689	50.6
21 0	158	585	- 482	392	.12	321	350	48.0
6000	845	1345	- 180	1158	.41	947	1021	48.1
22 0	160	595	- 900	402	.12	325	357	48.0
6000	843	1350	- 240	1159	.41	950	1024	48.0
23 0	166	606	- 960	410	.12	332	359	48.0
6000	850	1370	- 320	1171	.41	962	1034	48.4
24 0	155	613	- 1040	411	.12	332	365	48.0
6000	848	1370	- 523	1173	.41	955	1039	48.0
25 0	170	625	- 1175	419	.12	346	372	48.5
2000	406	900	- 1005	680	.21	570	596	49.2
4000	650	967	- 766	950	.33	660	884	47.9
6000	849	1390	- 570	1182	.41	970	1047	48.0
7000	947	1510	- 464	1301	.46	1060	1152	48.0
8000	1080	1689	- 318	1460	.52	1194	1290	48.1
9000	1253	1943	- 315	1669	.61	1395	1470	48.7
9400	1395	2170	- 310	1835	.69	1560	1530	48.8
9000	.1732	2650	-.0290	2510	.87	001820	.002300	49.2

BEAM 32

APPLD LOAD LBS.	ORIGINAL READINGS EXTENSOMETERS (inches) 1	3	2	4	DEFLECTIONS AT CENTER (inches)	UNIT DEFORMATIONS UPPER FIBRE	STEEL	NEUTRAL AXIS
1 0	0	0	0	0	87	0.00000	0.00000	
1000	0049	94	72	80	89	06	07	47.0
2000	152	204	174	200	94	16	16	49.0
3000	238	364	325	366	100	28	30	48.0
4000	432	532	465	543	105	42	45	48.5
5000	496	701	582	710	111	51	58	47.1
6000	591	886	661	890	117	64	68	48.6
3900	446	715	588	710	110	49	58	45.5
1000	149	405	290	390	100	22	30	40.3
0	23	263	167	236	94	12	20	34.0
2000	212	511	371	455	102	30	38	44.5
2 0	31	277	168	224	94	12	19	38.5
2000	242	534	370	465	102	34	38	47.5
4000	455	764	590	696	109	54	57	48.2
6000	590	998	816	930	118	67	74	46.2
4000	431	838	650	753	112	54	63	46.0
2000	214	620	425	519	105	35	43	44.5
3 0	-29	352	188	246	94	12	21	37.0
3000	313	742	518	623	108	46	51	47.0
6000	625	1072	840	958	118	74	75	48.0
3900	436	878	647	751	112	57	63	48.0
4 0	-11	379	194	250	95	15	21	42.0
3000	332	772	530	634	109	48	52	48.0
6000	649	1100	854	970	121	77	80	49.0
3000	369	817	562	666	112	52	54	49.1
5 0	001	405	201	256	96	17	21	45.0
3000	346	798	538	638	109	50	51	50.0
6000	655	1132	872	980	122	78	81	49.0
3980	487	948	681	780	115	64	63	50.1
6 0	11	426	201	258	97	19	20	48.4
3000	360	823	550	646	109	53	52	50.6
6000	672	1145	880	984	122	80	81	49.9
3000	391	864	580	677	112	56	54	51.0
7 0	25	441	206	260	97	21	20	51.0
3000	380	832	555	652	111	55	53	51.4
6000	690	1151	889	993	125	82	84	50.0
4000	501	963	688	787	115	65	65	50.8
8 0	31	446	209	253	97	21	20	50.5
3000	384	840	558	654	111	55	52	51.5
6000	704	1163	891	1000	124	83	82	50.5
3000	417	866	588	687	111	58	55	51.5
0	40	441	211	265	97	.00022	.00021	52.0

BEAM 32

APPLD LOAD LBS.	ORIGINAL READINGS EXTENSOMETERS (inches) 1	3	2	4	DEFLECTIONS AT CENTER (inches)	UNIT DEFORMATIONS UPPER FIBRE	STEEL	NEUTRAL AXIS
9 0	.0040	.0441	.0211	.0265	97	0.00022	0.00021	52.0
2000	265	701	430	519	106	44	41	52.0
4000	510	957	685	796	115	65	64	50.5
6000	709	1164	904	1013	125	83	83	50.0
2900	406	852	568	667	105	57	53	52.0
10 0	52	447	213	258	97	23	20	54.0
6000	629	1162	903	1010	125	78	85	47.8
11 0	119	438	216	268	99	27	20	51.0
6000	731	1164	903	1013	125	85	82	50.6
12 0	127	444	218	270	98	28	19	59.0
6000	797	1168	904	1017	125	89	82	52.0
13 0	136	443	220	272	98	28	20	59.0
6000	817	1180	914	1022	125	91	82	52.5
14 0	144	438	222	274	97	28	20	58.9
6000	829	1172	920	1026	125	90	82	52.0
15 0	231	467	231	278	99	36	18	66.2
6000	910	1199	934	1036	125	98	81	54.4
16 0	329	480	242	283	98	42	16	72.0
6000	1003	1222	943	1041	125	105	80	56.8
17 0	333	482	247	287	98	42	17	71.5
6000	1007	1212	950	1042	125	104	80	56.4
18 0	432	495	253	286	97	50	14	77.5
6000	1095	1244	958	1049	126	112	79	59.8
19 0	539	512	264	291	99	58	13	82.0
6000	1173	1264	968	1051	125	118	77	60.5
20 0	634	528	273	295	99	65	11	85.0
6000	1265	1283	975	1052	125	125	75	62.5
21 0	727	550	281	298	98	73	09	89.0
6000	1376	1304	987	1058	125	134	73	64.4
22 0	850	570	291	300	98	82	07	92.4
6000	1587	1324	993	1061	125	149	68	68.1
23 0	1011	597	298	305	98	94	04	95.5
6000	1632	1334	996	1061	125	153	67	69.0
24 0	1174	598	308	307	98	105	00	100.0
2000	1411	888	545	583	108	129	21	85.5
4000	1617	1149	802	850	117	148	46	76.2
6000	1774	1352	1013	1069	125	163	65	71.2
7000	1847	1469	1172	1189	129	170	80	67.7
8000	1847	1640	1258	1349	136	176	91	65.6
9000	1848	1844	1418	1532	144	182	109	62.2
9420	1901	1845	1522	1774	150	177	132	57.3
9800	2082	2572	2310	2420	177	206	206	50.0
8700	3131	4173	3482	3928	218	318	330	49.0
8000	.4687	.5960	.5045	.5593	——	.00477	.00456	51.0

BEAM 35

APPLD LOAD LBS.	ORIGINAL READINGS EXTENSOMETERS (inches) 1	3	2	4	DEFLECTIONS AT CENTER (inches)	UNIT DEFORMATIONS UPPER FIBRE	STEEL	NEUTRAL AXIS
1 0	0000	0000	0000	0000	000.00			
1000	.0110	104	0096	98	.05	0.000110	0.000082	57.0
2000	251	244	227	239	09	238	190	56.0
3000	420	415	382	403	.15	395	321	56.0
4000	614	611	551	580	.25	576	470	55.8
5000	842	843	705	759	.31	813	560	60.0
2950	671	667	538	588	.25	659	416	62.0
1000	409	412	303	338	.15	414	220	67.0
2 0	237	254	161	195	.03	248	110	70.0
2000	505	524	400	441	.18	500	305	63.0
4000	751	781	633	686	.30	721	505	59.8
5000	890	900	727	797	.34	869	570	61.0
3000	714	722	552	604	.27	711	415	64.0
1000	440	452	304	343	.15	455	200	69.0
3 0	267	288	163	200	.09	286	100	75.0
2000	556	573	411	460	.21	565	290	66.0
3000	683	704	531	587	.25	675	390	63.5
5000	827	948	752	813	.39	773	620	55.5
3000	733	753	565	616	.28	728	414	64.0
4 0	274	310	170	206	.10	293	102	74.0
2000	572	610	423	472	.21	581	300	66.0
5000	947	990	762	832	.38	928	580	62.0
2000	623	663	441	500	.25	640	300	68.0
5 0	284	332	160	205	.11	313	90	78.0
3000	721	774	544	610	.28	723	390	65.0
5000	969	1009	750	832	.38	965	550	64.0
2930	757	804	548	614	.29	770	380	67.0
6 0	296	350	156	204	.12	331	80	81.0
2000	600	659	415	476	.25	620	270	69.0
5000	974	1037	762	844	38	968	560	63.0
2000	647	708	439	509	.25	670	289	70.0
7 0	302	363	154	206	.12	341	70	83.0
3000	704	817	544	619	.28	700	400	64.0
5000	984	1052	768	852	.38	975	570	63.0
3000	787	852	518	639	.30	819	330	72.0
8 00	306	379	158	209	.12	344	90	82.0
2000	610	691	417	481	.24	632	170	70.0
5000	995	1078	741	831	.38	1000	530	66.0
1950	651	732	419	478	.25	680	260	73.0
9 0	309	393	148	185	.12	350	60	85.0
3000	751	848	548	604	.28	762	380	66.5
5000	986	1095	760	830	.38	1000	490	67.5
3000	788	887	564	618	.31	800	390	67.5
10 0	292	398	150	179	.12	0.000328	0.000080	82.0

BEAM 35 (continued)

	APPLD LOAD LBS.	ORIGINAL READINGS EXTENSOMETERS (inches) 1	3	2	4	DEFLECTIONS AT CENTER (inches)	UNIT DEFORMATIONS UPPER FIBRE	STEEL	NEUTRAL AXIS
10	0	.0292	.0398	.0150	.0178	12	0.000328	0.000080	82.0
	2000	609	721	424	466	25	628	280	69.0
	3000	744	860	550	595	30	754	395	71.0
	4000	864	985	655	685	34	865	470	65.0
	5000	979	1095	742	759	40	982	531	65.0
	4000	896	1001	658	657	34	893	459	66.0
	2000	641	764	435	416	25	668	280	71.0
11	0	287	405	138	101	12	330	60	85.0
	5030	987	1114	764	747	40	980	560	64.0
12	0	288	415	138	88	12	328	60	85.0
	5000	984	1116	740	676	40	982	530	65.0
13	0	300	428	124	24	12	350	30	92.0
	5000	998	1137	732	604	41	1010	510	66.0
14	0	300	428	117	-60	12	355	10	98.0
	5000	996	1138	749	560	41	1000	540	65.0
15	0	290	429	122	-105	12	338	34	91.0
	5000	997	1145	762	545	41	996	550	64.0
16	0	301	440	137	-119	12	343	50	87.0
	5000	994	1152	771	548	41	985	570	63.5
17	0	295	443	143	-114	12	338	50	85.0
	5000	997	1155	775	540	41	990	570	63.0
18	0	289	440	152	-136	12	316	100	76.0
	5000	995	1142	762	460	41	990	560	64.0
19	0	289	435	125	-213	12	340	30	91.0
	5000	996	1143	753	409	41	1000	540	65.0
20	0	285	438	127	-257	12	330	40	90.0
	5000	1001	1151	758	387	41	1000	550	65.0
21	0	282	437	122	-288	12	325	40	89.0
	5000	998	1150	751	+350	41	1000	540	65.0
22	0	283	440	115	-320	12	333	30	92.0
	5000	1008	1158	742	299	41	1020	520	66.0
23	0	300	441	106	-377	12	358	10	98.0
	2000	631	776	383	-84	25	675	220	75.5
	4000	887	1049	628	+156	36	907	420	68.0
	5000	1010	1162	737	270	41	1025	510	67.0
	3000	805	954	535	60	31	840	340	71.5
24	0	286	439	100	-400	12	342	5	99.0
	5000	1000	1154	735	260	41	1010	510	66.5
25	0	290	446	103	-409	12	348	10	98.0
	5000	1010	1170	745	240	41	1020	530	66.0
26	0	291	447	105	-440	12	348	10	98.0
	5000	1001	1168	747	200	42	1005	530	65.0
27	0	303	460	103	-476	13	362	0.000001	99.5
	5000	1021	1181	733	176	42	1040	505	66.2

APPLD LOAD LBS.	ORIGINAL READINGS EXTENSOMETERS (inches) 1	3	2	4	DEFLECTIONS AT CENTER (inches)	UNIT DEFORMATIONS UPPER FIBRE	STEEL	NEUTRAL AXIS
28 0	300	463	96	-499	0.12	0.000362	-0.000020	103.0
5000	1025	1189	741	+175	.42	1035	530	68.0
29 0	300	464	97	-504	.13	361	-11	102.0
5000	1029	1186	742	+172	.42	1050	510	68.0
30 0	311	466	95	-511	.13	378	20	103.0
1000	490	645	238	-351	.20	553	95	86.0
2000	657	816	381	-209	.26	712	200	78.0
3000	803	969	515	-62	.32	843	310	73.0
4000	934	1103	640	+60	.39	968	420	69.5
5000	1033	1180	730	+150	.42	1060	490	68.0
6000	1154	1304	838	+262	.47	1185	540	68.5
7000	1391	1543	1015	+424	.53	1410	700	66.5
7500	2270	2400	1438	+815	.79	2400	860	73.5
6000	3775	3850	2470	+1970	1.31	0.003960	0.001500	72.0